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DEPOSITIONAL ENVIRONMENTS AND HISTORY OF THE WINNIPEG GROUP (ORDOVICIAN), WILLISTON BASIN, NORTH DAKOTA

by
Stephen C. Thompson

Bachelor of Arts, Concordia College, 1976

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota

December
1984

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Department Geology

Degree Master of Science

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Signature Stephen C Thompson

Date Sept. 17, 1984

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ABSTRACT

The Winnipeg Group (Ordovician) in the Williston Basin, North Dakota, contains three formations. They are, in ascending order, the Black Island Formation, herein informally divided into lower and upper members, the Icebox Formation, and the Roughlock Formation. Strata of the Winnipeg Group (maximum thickness 400 ft., 122 m) represent the initial deposits of a Middle Ordovician craton-wide transgression. Throughout most of North Dakota, the Winnipeg is unconformably underlain by the Deadwood Formation (Upper Cambrian-Lower Ordovician) and conformably overlain by the Red River Formation (Upper Ordovician).

The strata of the lower member of the Black Island Formation consist of a red-bed lithofacies, containing reddish brown and dark greenish gray clayshale and reddish brown hematite-cemented quartz arenite, and a green quartz wacke lithofacies, composed of greenish gray, friable, quartz wacke. The upper member of the Black Island has been divided into a quartz arenite lithofacies, composed of thickly bedded, medium to light gray, quartz arenite and bioturbated quartz wacke, and a green quartz wacke which is similar in lithology to the green quartz wacke of the lower member. The Icebox Formation is composed mostly of greenish gray, noncalcareous, in places bioturbated and fossiliferous clayshale. The Roughlock Formation consists mostly of argillaceous, fossiliferous, nodular limestone.

Rocks of the red-bed lithofacies of the lower member of the Black Island Formation are interpreted to have been deposited on a deltaic plain. The quartz arenite lithofacies of the upper member of the Black Island is interpreted to be a nearshore deposit. The green quartz wacke lithofacies of both the lower and upper members is considered to be

transitional between the deltaic plain and nearshore deposits and may be the initial deposits of the Middle Ordovician transgression. Rocks of the Icebox Formation are interpreted to have been deposited in an offshore environment. Bioturbation and fossils indicate that mild oxidizing conditions existed in the uppermost Icebox sediments. Rocks of the Roughlock Formation were also deposited in an offshore environment. Reduction in detrital sedimentation permitted the transition from the clayshale of the Icebox to the argillaceous limestone of the Roughlock. A further reduction in detrital input resulted in the transition from the Roughlock to the limestone of the Red River Formation. The formations of the Winnipeg Group are at least partial facies equivalents of each other. Intertonguing between the lower and upper members of the Black Island and between the upper member of the Black Island and the Icebox substantiates the existence of a facies relationship between these units.

Isopach maps, sandstone-shale ratio maps, and kaolinite-illite ratio maps suggest that the Middle Ordovician marine connection to North Dakota was to what is now the southeast through Minnesota rather than to the present southwest, as was previously assumed. This implies a sag or break in the Transcontinental Arch at that time.

Cross sections of the Deadwood Formation and of formations of the Winnipeg Group, together with isopach maps of those units, suggest that the initiation of subsidence of the Williston Basin coincided with the beginning of Winnipeg sedimentation. The area of greater thickness of the underlying Deadwood Formation near the center of the Williston Basin is due, at least partially, to post-depositional erosion of the Deadwood rather than to subsidence during Deadwood deposition.

INTRODUCTION

General

Ordovician strata of the Winnipeg Group in North Dakota are becoming better understood with the continued drilling of deep oil wells within the Williston Basin. At the time of the last significant published work on the Winnipeg in North Dakota (Carlson, 1960), only 127 wells had penetrated the Winnipeg. Most of these early wells were located in the eastern part of the state. Since that time, about 150 additional testholes have penetrated strata of the Winnipeg, with most of these concentrated in western North Dakota. This increased control has provided opportunity for a better understanding of the Winnipeg Group than was previously possible.

Purpose

The purpose of this study is to describe the lithologic character of the rocks of the formations of the Winnipeg Group, to interpret the environments in which these rocks were deposited, and to interpret the depositional history. This study will also attempt to clarify recognition of the the boundary between the Deadwood Formation and the Black Island Formation at the base of the Winnipeg Group.

Geologic Setting

Regional Stratigraphy

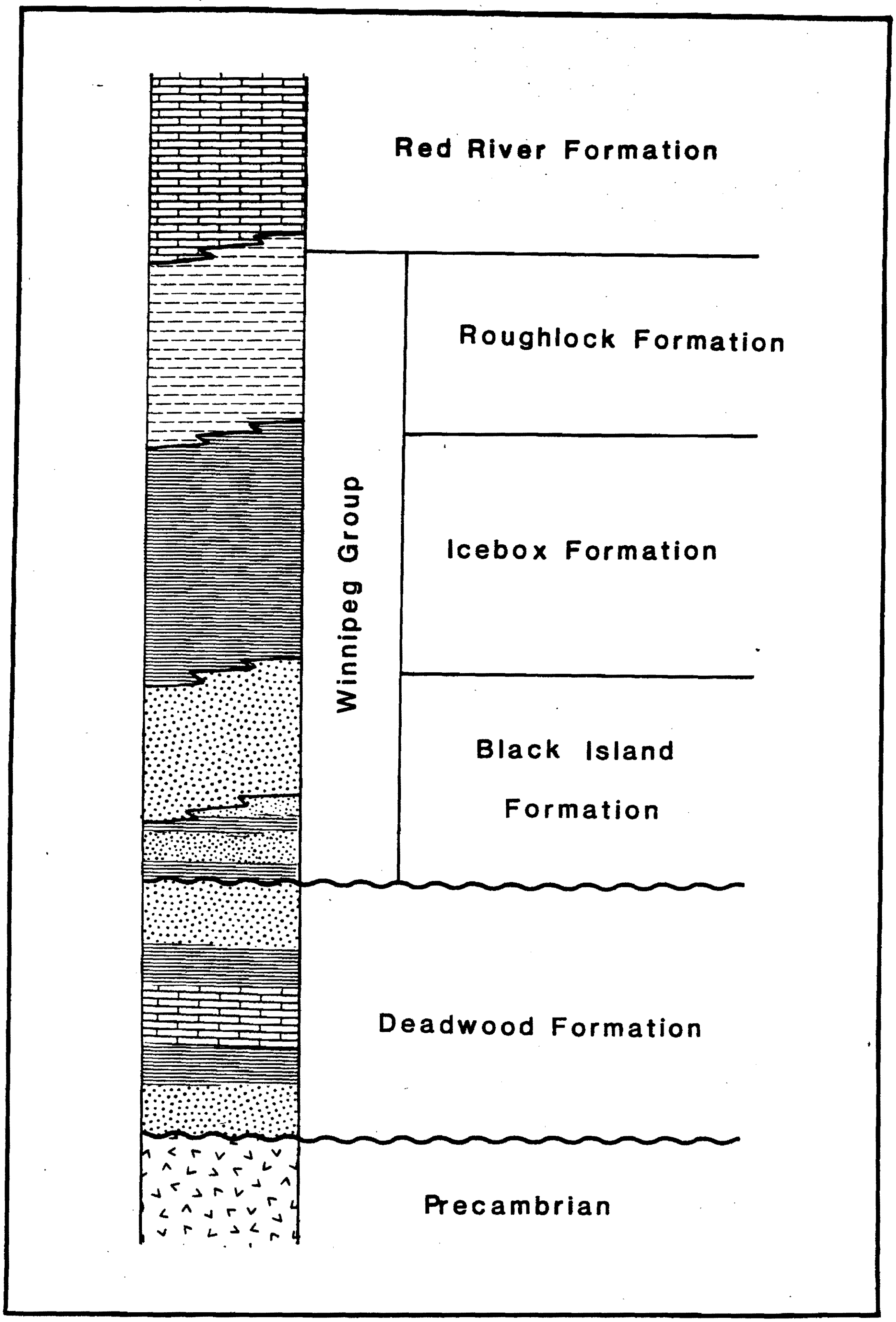
The Winnipeg Group, of Ordovician age, consists of three formations, in ascending order the Black Island Formation, the Icebox Formation, and the Roughlock Formation (Fig. 1). The Black Island reaches a maximum thickness of 250 feet (76 m) and is composed of sandstone and shale. Overlying the Black Island is the noncalcareous, green to gray, occasionally fossiliferous and bioturbated clayshale of the Icebox Formation. The Icebox reaches a maximum thickness of 160 feet (49 m). The upper formation in the Winnipeg Group, the Roughlock Formation, attains a maximum thickness of 90 feet (27 m). Throughout most of North Dakota, the Roughlock is composed of argillaceous, fossiliferous, nodular limestone.

Throughout most of the state, the Winnipeg Group disconformably overlies the sandstone, shale, and carbonate of the Deadwood Formation. In eastern North Dakota, the Winnipeg nonconformably overlies Precambrian rocks. The Winnipeg conformably underlies the dolomitic limestones of the Red River Formation.

The Winnipeg occurs throughout most of North Dakota and portions of South Dakota, Wyoming, Montana, Saskatchewan, Manitoba, and the northwestern corner of Minnesota (Fig. 2). The Winnipeg is thickest in western North Dakota. It crops out in four areas along the margins of its areal extent: in the Bighorn Mountains, in the northern Black Hills, in east-central Saskatchewan, and in islands and along the shores of Lake Winnipeg in Manitoba (Fig. 2).

The diagrammatic cross section shown in Figure 3 illustrates the relationships, as suggested in the present study, between the formations

Figure 1. Diagrammatic lithologic column of the Winnipeg Group and adjacent formations.



Red River Formation
Roughlock Formation
Icebox Formation
Winnipeg Group
Black Island Formation
Deadwood Formation
Precambrian

Figure 2. The position and extent of the Williston Basin and areal extent of the Winnipeg Group. The outline of the Williston Basin was taken from Laird (1956, p. 16); the boundary between the Churchill and Superior Provinces was taken from Gerhard and others (1982).

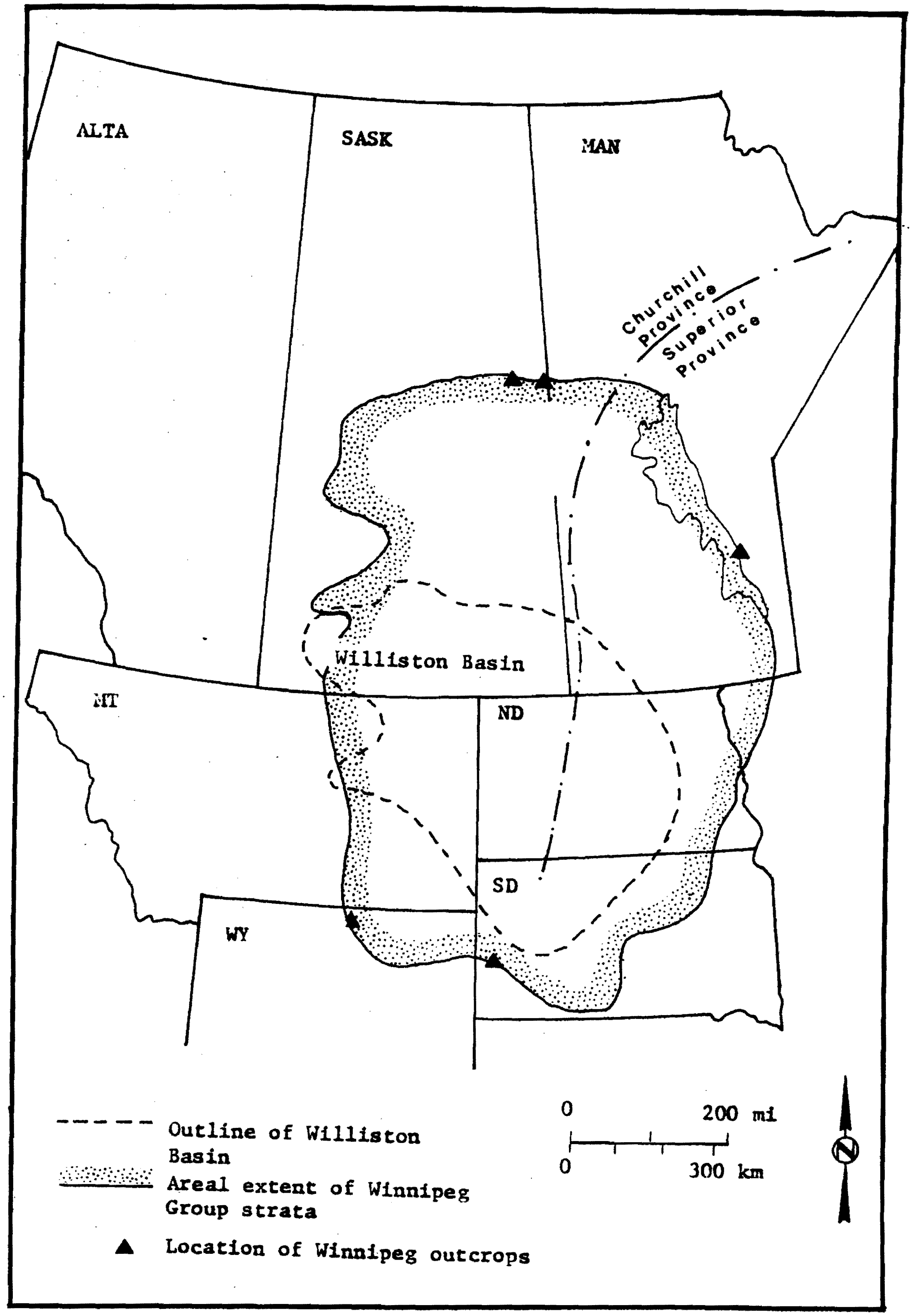
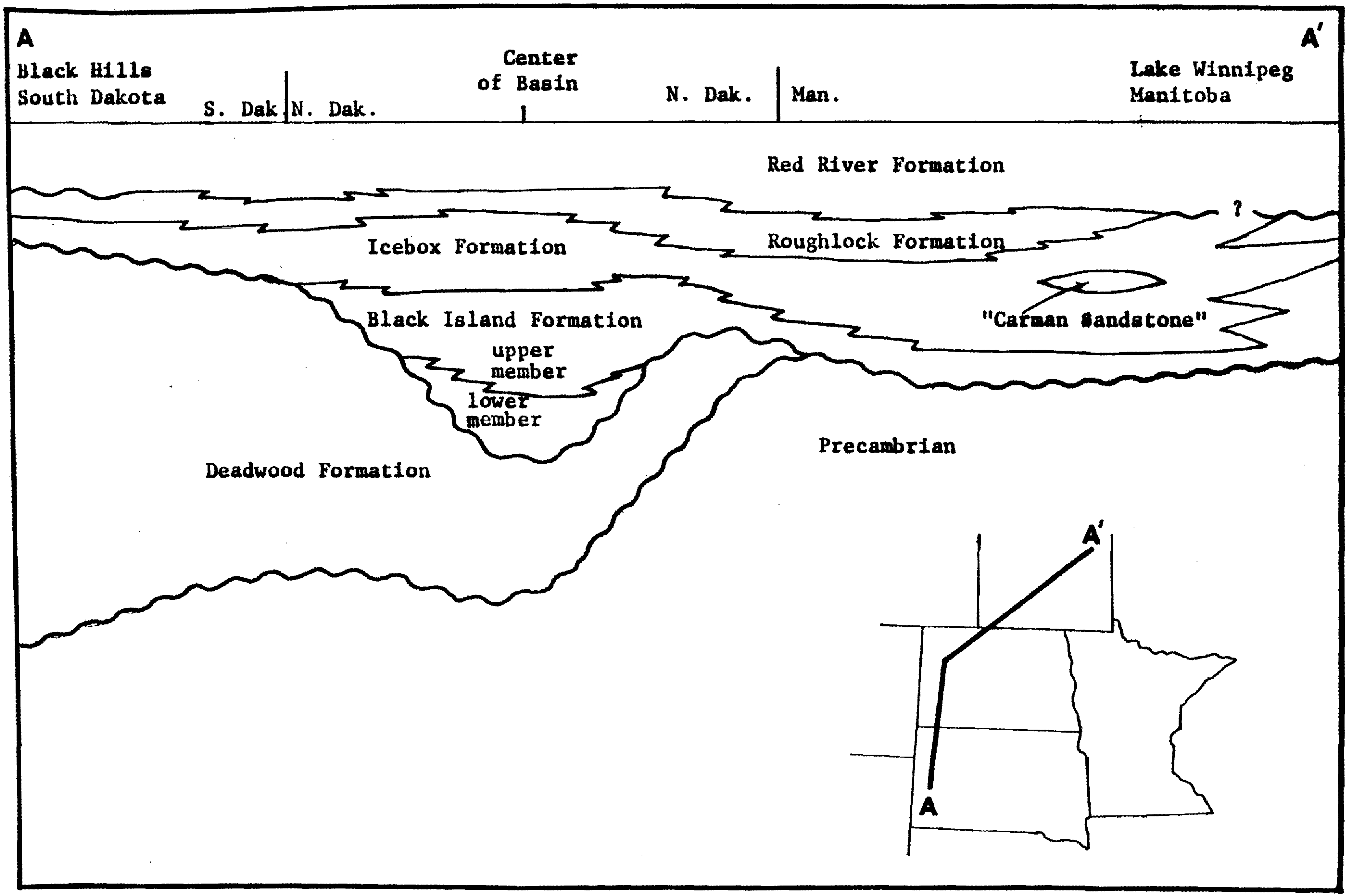

ALTA
SASK
MAN
Churchill Province
Superior Province
Williston Basin
MT
ND
SD
WY
Outline of Williston Basin
Areal extent of Winnipeg Group strata
Location of Winnipeg outcrops
0
200 mi
0
300 km
N

Figure 3. Diagrammatic cross section of the Winnipeg Group from South Dakota to Manitoba.


A
A'
Black Hills
South Dakota
S. Dak
N. Dak.
Center
of Basin
N. Dak.
Man.
Lake Winnipeg
Manitoba
Red River Formation
?
Icebox Formation
Roughlock Formation
Black Island Formation
upper
member
lower
member
"Carman Sandstone"
Deadwood Formation
Precambrian
A'
A

of the Winnipeg Group and adjacent formations. Figure 3 is a schematic cross section from the Black Hills, South Dakota, to the Lake Winnipeg, Manitoba, type area, through the center of the Williston Basin. The Deadwood Formation pinches out to the east and northeast so that in southern Manitoba the Winnipeg Group rests nonconformably on Precambrian rock. The Black Island is thickest in the center of the Williston Basin and thins southward to disappear near the North Dakota-South Dakota boundary. The Black Island Formation can be divided into two members and the lower member is present only in the center of the basin. Near the northeastern margin of the basin, sandstone of the Black Island and clayshale of the Icebox intertongue (Fig. 3). Throughout most of North Dakota and Manitoba the Icebox Formation overlies the Black Island, but in South Dakota, where the Black Island is absent, the Icebox disconformably overlies the Deadwood Formation. The Roughlock is conformable with both the underlying Icebox and the overlying Red River Formation throughout most of its extent.

Regional Structure

The geology of the northern Great Plains is dominated by the presence of the Williston Basin (Fig. 2). It is a wide, shallow, structural and sedimentary basin, centered in northwestern North Dakota, and it encompasses about 50,000 square miles (129,500 square km) in North Dakota, South Dakota, Montana, Saskatchewan, and Manitoba (Carlson and Anderson, 1965, p. 1833). The outline of the Williston Basin shown on Figure 2 is drawn at the zero elevation line on the Dakota Sandstone, as suggested by Laird (1956, p. 15). A thickness of approximately 16,000 feet (4900 m) of sedimentary rock is present in the deepest part of the Williston Basin, in McKenzie County, North Dakota. The Canadian Shield, which is exposed at the surface in northern Saskatchewan, northeastern Manitoba, and northern Minnesota, extends beneath the Williston Basin. Ballard (1963, p. 30) recognized the boundary of the Precambrian Churchill and Superior Provinces as extending north-south through central North Dakota. Gerhard and others (1982, p. 991) have suggested that the boundary between the Superior and Churchill Provinces was an important influence in the development of the basin in Phanerozoic time.

Present-day major structures of the Williston Basin are shown on Figure 4. Gerhard and others (1982, p. 989-1020) have provided a thorough discussion of the tectonic setting and general stratigraphy of the Williston Basin.

Previous Work

Lithostratigraphy

Dowling (1895, p. 67) was the first to describe strata now assigned to the Winnipeg Group. Referring to the unit as the "Winnipeg sandstone" he reported exposures of about 100 feet (30 m) on eastern islands of Lake Winnipeg. Although the lower part of the Winnipeg was described as a fine-grained, friable sandstone, Dowling (1895, p. 67) noted deposits of dark green shale in the upper part. In 1900, Dowling (p. 35) referred to these rocks as the "Winnipeg formation" (Fig. 5) and, using paleontologic evidence, assigned (p. 39) the unit an age transitional from "Black River" to "Trenton".

Figure 4. Major structural features in western North Dakota and eastern Montana (modified from Gerhard and others, 1982).

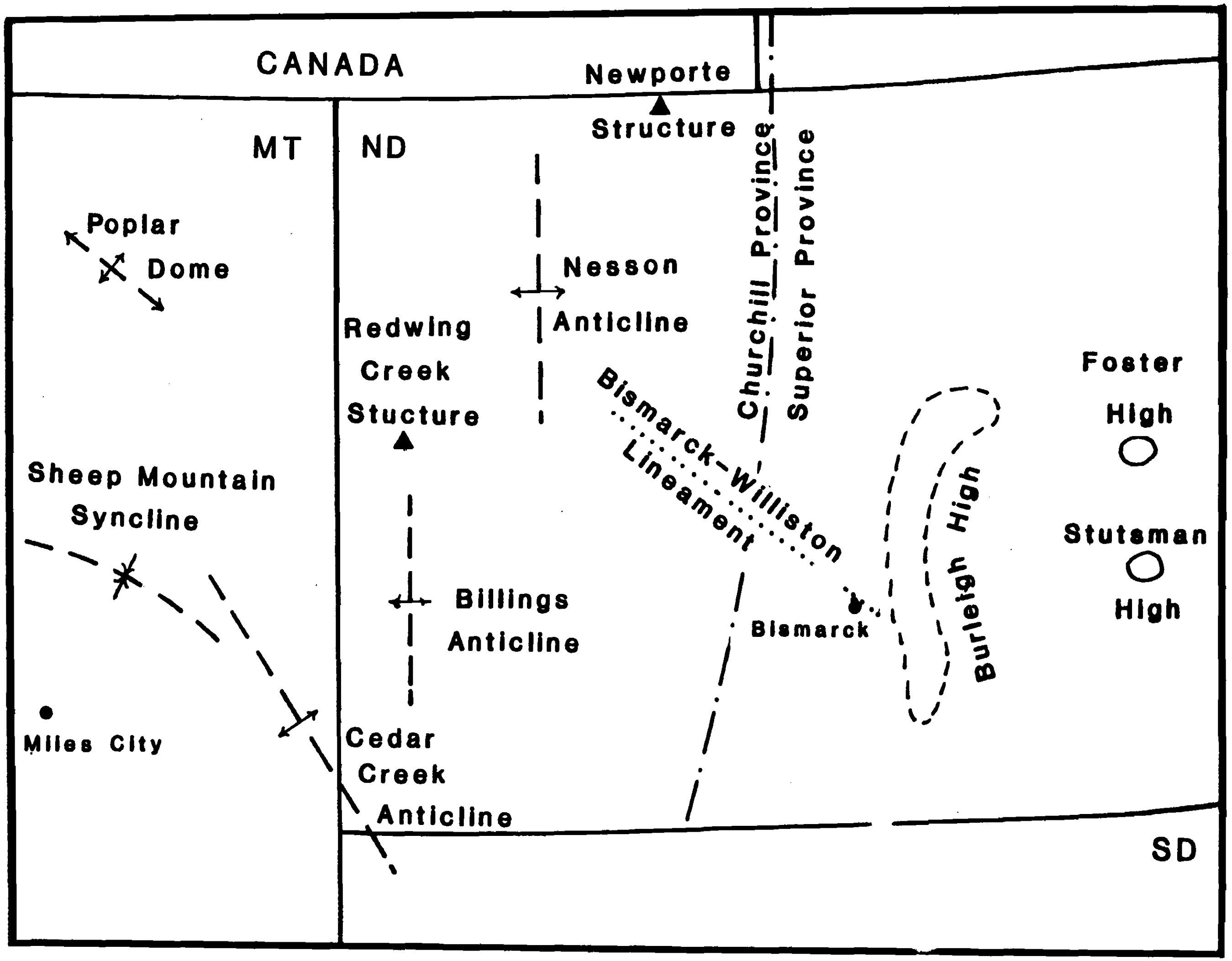

CANADA
Newporte
Structure
MT
ND
Poplar
Dome
Nesson
Anticline
Redwing
Creek
Stucture
Churchill Province
Superior Province
Bismarck-Williston
Lineament
Foster
High
Stutsman
High
Burleigh High
Sheep Mountain
Syncline
Billings
Anticline
Bismarck
Miles City
Cedar
Creek
Anticline
SD

Figure 5. Stratigraphic nomenclature from 1895 to 1959 for strata now included in the Winnipeg Group.

<table>
<tr><th>Dowling
(1900)
Man.</th><th>Laird
(1941)
No. Dak.</th><th colspan="2">Baillie
(1952)
Man.</th><th>McCoy
(1952)
So. Dak.</th><th colspan="2">Genik
(1954)
Man.</th><th colspan="2">Parks
and Ambler
(1956)
Man. and Sask.</th><th colspan="2">Andrichuk
(1959)
Man.</th></tr>
<tr><td>Red River formation</td><td>Red River formation</td><td colspan="2">Red River formation</td><td>Whitewood formation</td><td colspan="2">Red River formation</td><td colspan="2">Red River formation</td><td colspan="2">Red River formation</td></tr>
<tr><td rowspan="4">Winnipeg formation</td><td rowspan="4">Winnipeg formation</td><td rowspan="4">Winnipeg formation</td><td rowspan="2">upper unit</td><td>Roughlock formation</td><td rowspan="4">Winnipeg formation</td><td rowspan="2">Deer Island member</td><td rowspan="4">Winnipeg formation</td><td rowspan="2">Winnipeg Shale</td><td rowspan="4">Winnipeg formation</td><td rowspan="2">upper 100 feet</td></tr>
<tr><td rowspan="2">Icebox formation</td></tr>
<tr><td rowspan="2">basal sandstone unit</td><td rowspan="2">Black Island member</td><td rowspan="2">Winnipeg Sandstone</td><td rowspan="2">lower portion</td></tr>
<tr><td>Aladdin sandstone</td></tr>
<tr><td>Precambrian</td><td>Deadwood formation</td><td colspan="2">Precambrian</td><td>Deadwood formation</td><td colspan="2">Deadwood formation</td><td colspan="2">Deadwood formation</td><td colspan="2">Deadwood formation</td></tr>
</table>

In 1936, Furnish and others (p. 1333) reported Middle Ordovician scolecodonts and conodonts in the uppermost shale and siltstone beds of the Deadwood Formation at the type section, near Deadwood, South Dakota. On this basis, they transferred (p. 1341) the shale and siltstone beds located above the "Scolithus sandstone" from the Deadwood to the overlying Whitewood Formation (Middle Ordovician).

In 1941, Laird (p. 25) used the term Winnipeg in the subsurface of northeastern North Dakota for the first time (Fig. 5); in that paper 130 feet (40 m) of shale and five feet (1.5 m) of sandstone overlying Precambrian granite from a well near Hamilton, North Dakota, were identified as Winnipeg and "Deadwood?" respectively. In his study of the subsurface geology of south-central North Dakota, Towse (1952, p. 6) placed all pre-Red River rocks in the "Winnipeg formation" of Ordovician age. Baillie (1952 p. 11) divided the "Winnipeg formation" of the type area into two units; 45 feet (13.7 m) of basal sandstone overlain by 35 feet (10.7 m) of shale, sandstone and arenaceous shale (Fig. 5). He defined (p. 10) the Winnipeg as including all the rocks underlying the carbonate of the Red River Formation and overlying Precambrian basement rocks in the Lake Winnipeg area.

In 1952 McCoy formally named as formations the "'Skolithos' sandstone" of the Deadwood Formation and the shale and siltstone members underlying the dolomitic limestone of the Whitewood Formation. He named the "'Skolithos' sandstone" the "Aladdin formation", the overlying shale the "Icebox formation", and the overlying siltstone the "Roughlock formation" (Fig. 5). The type sections for all of these three formations are in the northern Black Hills, South Dakota. McCoy (1952, p. 44) indicated that the Roughlock disappeared just north of the Black

Hills due to nondeposition. On the basis of the conodont fauna, he assigned (1952, p. 45) a Trentonian age to the Roughlock and (p. 46) a "Black River" age to the Icebox. Although the rocks which compose the Aladdin had been previously considered Cambrian in age, McCoy stated that the Aladdin was of Middle Ordovician age.

In his study of the Ordovician and Silurian stratigraphy of east-central Saskatchewan, Kupsch (1953, p. 12) reported the "Winnipeg formation" in that region to consist largely of "sand" with minor amounts of shale. Kupsch (p. 11) subdivided the Winnipeg into three "units" based on the Winnipeg section exposed on the shores and islands of the southern part of Lake Winnipeg, Manitoba, as described by Genik (1951). At the base, Kupsch (1953) recognized a "Black Island unit", composed of 100 feet (30 m) of unfossiliferous "sand", overlain by a "Grindstone Point unit", a sandstone and shale sequence, and topped by a "Deer Island unit", consisting of sandstone grading into dolomite.

In his regional study of the "Winnipeg formation", Genik (1954, p. 3) named the basal sandstone of the type area the "Black Island member" and the overlying more shaly beds the "Deer Island member" of the Winnipeg (Fig. 5). Genik (1954, p. 2) extended the usage of the term Winnipeg to include subsurface beds in North Dakota and rocks cropping out in the Black Hills of South Dakota. He called (1954, p. 2) the Aladdin Formation of the Black Hills the Black Island Member, and the "Icebox and Roughlock formations" of the Black Hills the "Deer Island member of the Winnipeg formation". Twenhofel and others (1954, p. 281) suggested that the "Winnipeg sandstone" was the initial deposit of the transgression which later deposited the "Red River formation".

Since no formal type section had ever been established for the

Winnipeg, Macauley (1955, p. 49) suggested using cores from the following wells as "type sections" for the Winnipeg: California Standard Daly No. 15-18 in Lsd. 15, Sec. 18, T. 10, R. 27, W. 1st Mer. in Manitoba or the Union Aanstad No. 1, Sec. 29, T. 158 N., R. 62 W. in North Dakota. Macauley (1955, p. 52) noted the similarity between the lithology of the St. Peter Sandstone and that of the basal sandstone of the Winnipeg but suggested a significant age difference and proposed (p. 52) an early Cincinnatian age for the Winnipeg.

Stocker (1956, p. 113) studied the pre-Red River rocks in the Williston basin and divided them into the Deadwood and Winnipeg Formations. He subdivided the Winnipeg into three units: a lower "Winnipeg sandstone" and an upper "Winnipeg shale". He also reported another sandstone within the Winnipeg Formation overlying the "Winnipeg shale" in southern North Dakota.

In their study of the Winnipeg and Deadwood in southern Manitoba and Saskatchewan, Parks and Ambler (1956, p. 116) subdivided the Winnipeg into a lower "Winnipeg Sandstone" and an upper "Winnipeg Shale" (Fig. 5). They showed (p. 119) that the upper shale offlaps the sandstone of the Winnipeg in north-central Saskatchewan.

Ross (1957, p. 460) included fossils from the Winnipeg Formation in his study of the Ordovician from the Williston Basin in Montana. Although he encountered scales and plates of fishes, he reported no fossils which could serve as strict time-stratigraphic indicators.

Andrichuk (1959) studied the Winnipeg Formation and other lower Paleozoic rocks in southern Manitoba. He arbitrarily divided (p. 2347) the Winnipeg into two portions: the upper 100 feet (30 m) and whatever portion remained beneath (Fig. 5). He noted (p. 2347) a large, elongate, east-west trending sandstone body within the shale of the Winnipeg in southeastern Manitoba. Calling this lithosome the "Carman sand body", he suggested (p. 2354) that it might have been originally deposited as an offshore bar.

In his study of the stratigraphy of the Deadwood and Winnipeg in North Dakota and surrounding states and provinces, Carlson (1960, p. 9) also extended the usage of the name Winnipeg to include the rocks of the Icebox and Roughlock in the Black Hills. He proposed that the Winnipeg Formation in North Dakota be divided into three members: Black Island at the base, overlain by the Icebox and topped by the Roughlock (Fig. 6). Carlson (1960, p. 51) concluded that the Black Island was absent in the Black Hills and suggested that McCoy's "Aladdin formation" (called the Black Island by Genik, 1954) was merely an insignificant part of the Deadwood Formation.

In his study of the Winnipeg in Saskatchewan, McLean (1960, p. 10) divided the Winnipeg into a lower unit of quartzose sandstone and an upper unit of shale interbedded with sandstone lenses. McLean (1960, p. 24) considered the upper unit to be continuous with the Icebox Member (as used by Carlson, 1960) and showed (p. 10) that the upper unit offlaps the lower unit in north-central Saskatchewan.

In his study of Ordovician deposits of the Williston Basin, Fuller (1961, p. 1339) referred to the Winnipeg as a group with two "units" in the interior of the basin; a basal sandstone and an "upper unit". Fuller (1961) believed the lowest sandstone of the Winnipeg Group in the Williston Basin (the "Black Island member" of Carlson, 1960) to be at a different stratigraphic level than the basal sandstone at the Manitoba outcrop and objected to Carlson's (1960) correlation. He suggested

Figure 6. Stratigraphic nomenclature from 1960 to the present for strata now included in the Winnipeg Group.

Carlson (1960) No. Dak.	Fuller (1961) No. Dak and Man.	Carlson (1964) No. Dak.	Peterson (1971) Sask.	Vigrass (1971) Man.	McCabe (1978) Man.	Carlson and Thompson (in press) This Paper
Red River formation	Red River formation	Red River Formation	Red River Formation	Red River Formation	Red River Formation	Red River Formation
Winnipeg formation	Winnipeg group	Winnipeg Group	Winnipeg Formation	Winnipeg Formation	Winnipeg Formation	Winnipeg Group
Roughlock member	upper unit	Roughlock Formation	Icebox Member	upper unit	upper 50 percent	Roughlock Formation
Icebox member	basal sandstone unit (Man.)	Icebox Formation				Icebox Formation
Black Island member	Burgen sandstone unit (No. Dak.)	Black Island Formation	Black Island Member	lower unit	lower 50 percent	Black Island Formation
Deadwood formation	Deadwood formation	Deadwood Formation	Deadwood Formation	Deadwood Formation	Deadwood Formation	Deadwood Formation

importing the name "Burgen sandstone", the basal sandstone of the Simpson Group in Okalahoma, for the basal sandstone of the Winnipeg in the Williston Basin (Fig. 6).

Carlson (1964), in his study of the Winnipeg in eastern North Dakota, elevated the Winnipeg from formational to group status and considered the Black Island, Icebox, and Roughlock to be formations of that group (Fig. 6). He reported sandstone and limestone lenses within the shales of the Icebox Formation of extreme eastern North Dakota.

In his study of the Winnipeg Formation of Saskatchewan, Paterson (1971, p. 7) followed the nomenclature of Carlson (1960). He recognized two members, the Black Island and the Icebox and believed the third member, the Roughlock, to be absent in Saskatchewan although present in North Dakota (Fig. 6). Paterson (1971, p. 10) showed the Icebox offlapping the Black Island in the southeastern portion of Saskatchewan. Where the Black Island overlies the Deadwood Formation, Paterson (1971, p. 11) differentiated the two on the basis of the presence of glauconite and mica in the Deadwood. Another means he used to differentiate the two was the greater radioactivity of the Deadwood than the Black Island as recorded by the gamma ray log.

Vigrass (1971, p. 225) studied the Winnipeg Formation in Manitoba and eastern Saskatchewan and, using samples and mechanical logs, divided it into an upper and a lower unit (Fig. 6). Within each of these two units, he mapped a basin-margin, sandstone facies rimming the basin, an offshore, mudstone facies toward the south and the center of the basin, and a "transition facies" of intertongued sandstone and mudstone occurring between the other two facies. He found the upper unit to be more transgressive than the lower unit. The "Carman Sandstone" was said to be located within Vigrass' upper unit within the mudstone facies. Vigrass (1971 p. 232) suggested that the "Carman Sandstone" is comparable to modern, outer-shelf sand bodies and that it was deposited up to 100 miles (160 km) offshore by the tractive action of a coastal current. Vigrass (p. 233) also suggested that minor regressions occurred during the time of the deposition of his lower unit, which was finally completed by a general regressive phase. He described the deposition of the upper unit as beginning with a strong transgression but also sustaining minor regressive phases. He viewed (p. 233) Winnipeg deposition as having been completed when the sources of Winnipeg clastics were covered by the general Ordovician transgression which later deposited the Red River.

Foster (1972, p. 76), in his overview of the Ordovician System in the western United States, used the nomenclature suggested by Carlson (1964) in which the Winnipeg Group was divided into the Black Island, Icebox and Roughlock Formations. Foster (1972, p. 76) also agreed with Carlson (1960) that, although they are of different ages, the basal sandstone of the Winnipeg in the Williston Basin is a part of the same rock-stratigraphic unit as the basal sandstone of the Winnipeg in outcrop in Manitoba. Foster (1972, p. 77) suggested that the Middle Ordovician rocks in the Bighorn Mountains are physically connected with rocks of the Winnipeg Group. He therefore suggested that the Middle Ordovician rocks of the Bighorns should be referred to as Winnipeg rather than as the Harding Formation as erosion has separated these rocks from the type area of the Harding in Colorado.

Ross (1976, p. 74), in his paper on Ordovician sedimentation in the western United States, considered the Transcontinental Arch to be a major barrier during Middle Ordovician time. He suggested that the arch may have extended unbroken from northeastern Minnesota to southwestern Nebraska.

In the report on a uranium-exploration drilling project, Moore (1978) logged and described Winnipeg strata in eastern North Dakota and northwestern Minnesota. He established the eastern erosional limit and the erosionally truncated portion of the Winnipeg.

In 1980, Witzke studied the paleogeography of the Winnipeg "Formation" and other Middle and Upper Ordovician formations along the Transcontinental Arch. He noted (p. 8) the similarities between lithologies in the Winnipeg and the St. Peter Sandstone but maintained that the two units must have been separated by the Transcontinental Arch.

Nomenclature

As illustrated by the preceding discussion of previous work, nomenclature has been a continuing problem for geologists working on Winnipeg Group strata. Much of the early work on the Winnipeg was done in the areas where the Winnipeg cropped out -- in the Lake Winnipeg area and in the Black Hills, South Dakota. The predominance of clastics at the outcrop localities suggests that Winnipeg strata in outcrop may be basin-marginal deposits and that facies changes might be expected to occur in these rocks as they are traced into the subsurface toward the center of the basin. For this reason, many geologists have objected to extending names used in areas of outcrop into the subsurface. Some geologists have divided the Winnipeg in the subsurface into informal upper and lower units (Andrichuk, 1959; Vigrass, 1971; McCabe, 1978), while others have used the informal terms, "Winnipeg sandstone" and "Winnipeg shale" (Parks and Ambler, 1956; Anderson, 1982; Bolyard, 1983). Bitney (1983) used a mixture of terms to name the Winnipeg, including a "basal Winnipeg Sandstone", a "Winnipeg shale", and an "upper transitional member". Use of terms such as "Winnipeg sandstone" and "Winnipeg shale" for different units (or parts of the same unit) is at variance with the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983, p. 852); this practice may also lead to confusion when a sandstone lithosome is present within a shale as within the Winnipeg Group. The three formations used in this study, the Black Island, Icebox, and Roughlock, meet the criteria necessary (North American Commission on Stratigraphic Nomenclature, 1983, p. 858) for formational rank. They are identifiable by their lithic characteristics and stratigraphic position, and they are mappable in the subsurface.

Fuller (1961, p. 1339) rejected the term Black Island as a name for the basal sandstone in center of the Williston Basin. He felt that the basal sand in the center of the basin was located on a different stratigraphic level than the Black Island Sandstone on the shores of Lake Winnipeg, Manitoba. McCabe (1978, Plate 1) demonstrated that the basal sandstone of the Winnipeg Group in the center of the Williston Basin is lithologically continuous from North Dakota to within about 60 miles (100 km) of the type area of the Black Island in Manitoba. If Fuller meant "different stratigraphic level" to imply that the basal sandstone transgressed time horizons as an argument for changing the nomenclature, the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, p. 856) makes it clear that lithostratigraphic units are independent of time and transgression of time by a lithostratigraphic unit is not a rationale for a change in nomenclature. Since McCabe (1978) demonstrated that the basal sandstone was probably physically continuous from the outcrop area into the subsurface, the name Black Island is acceptable for use in the Williston Basin.

Walter C. Sweet (written communication, 1984) objected to using the name Roughlock for the argillaceous limestone underlying the Red River Formation in eastern North Dakota. Sweet stated that he could not agree that the "shaly-carbonate sequence" of eastern North Dakota "is a chronostratigraphic equivalent of the South Dakota Roughlock Formation any more than it is the lithic equivalent of that unit".

The first of Sweet's objections, that the South Dakota Roughlock Formation is not the chronostratigraphic equivalent of the sub-Red River argillaceous limestone of the Williston Basin, has no bearing on the lithostratigraphic nomenclature. According to the North American Commission on Stratigraphic Nomenclature (1983, p. 856), lithostratigraphic units are independent of time concepts; and, indeed, the boundaries of most lithostratigraphic units may transgress time horizons.

The second of Sweet's objections may be valid. As stated in the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983, p. 856) in Article 23 (b), "where a unit changes laterally through abrupt gradation into, or intertongues with, a markedly different kind of rock, a new unit should be proposed for the different rock type". The Stratigraphic Code also states, in Article 22 (b), "the naming of new units in the subsurface is justified only where the the subsurface section differs materially from the surface section". Using well logs, Clarence G. Carlson (personal communication, 1984) has been able to trace the Roughlock in the subsurface from near the Black Hills in South Dakota, northeastward into North Dakota. He noted that the Roughlock undergoes a facies change from a siltstone or sandstone to an argillaceous limestone near the South Dakota-North Dakota border.

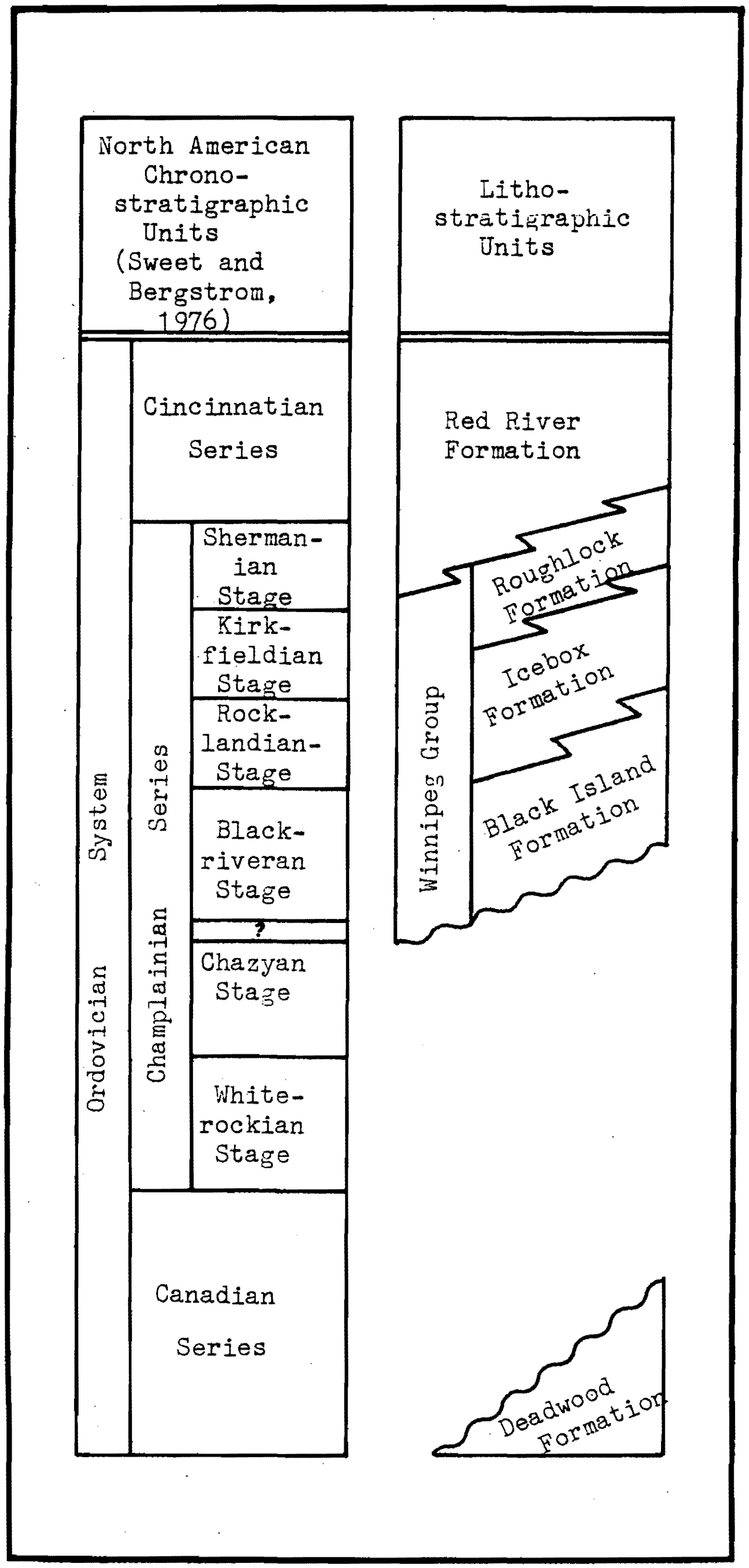
The question of whether to rename the Roughlock argillaceous limestone of the subsurface in North Dakota hinges on whether it differs "materially" from the surface section, where it is composed of siltstone. Much of the Roughlock of the Williston Basin is a highly argillaceous limestone with some calcareous shale, and it may not be sufficiently different from the Roughlock at the type section in the Black Hills, South Dakota, to warrant a change in nomenclature. This study will continue the nomenclature of the North Dakota Geological Survey (Bluemle and others, 1980) and use the term Roughlock for all rocks overlying the Icebox and underlying the Red River Formation.

Age

Recent evidence (Walter C. Sweet, written communication, 1984) suggested that Winnipeg Group strata may be Late Ordovician as well as Middle Ordovician in age. As suggested in Figure 7, rocks of the Winnipeg may range in age from the Chazyan to the Edenian age of the Cincinnatian. Figure 7, with its diagonal lines of lithostratigraphic contact, also illustrates the time-transgressive nature of these units.

Twenhofel and others (1954, Plate 1) indicated that they interpreted the "Winnipeg sandstone" in Manitoba to be of Richmondian

Figure 7. Generalized age relationships of Winnipeg Group strata in North and South Dakota.


North American Chrono-stratigraphic Units (Sweet and Bergstrom, 1976)
Litho-stratigraphic Units
Ordovician System
Cincinnatian Series
Champlainian Series
Shermanian Stage
Kirkfieldian Stage
Rocklandian-Stage
Blackriveran Stage
?
Chazyan Stage
Whiterockian Stage
Canadian Series
Red River Formation
Roughlock Formation
Icebox Formation
Black Island Formation
Winnipeg Group
Deadwood Formation

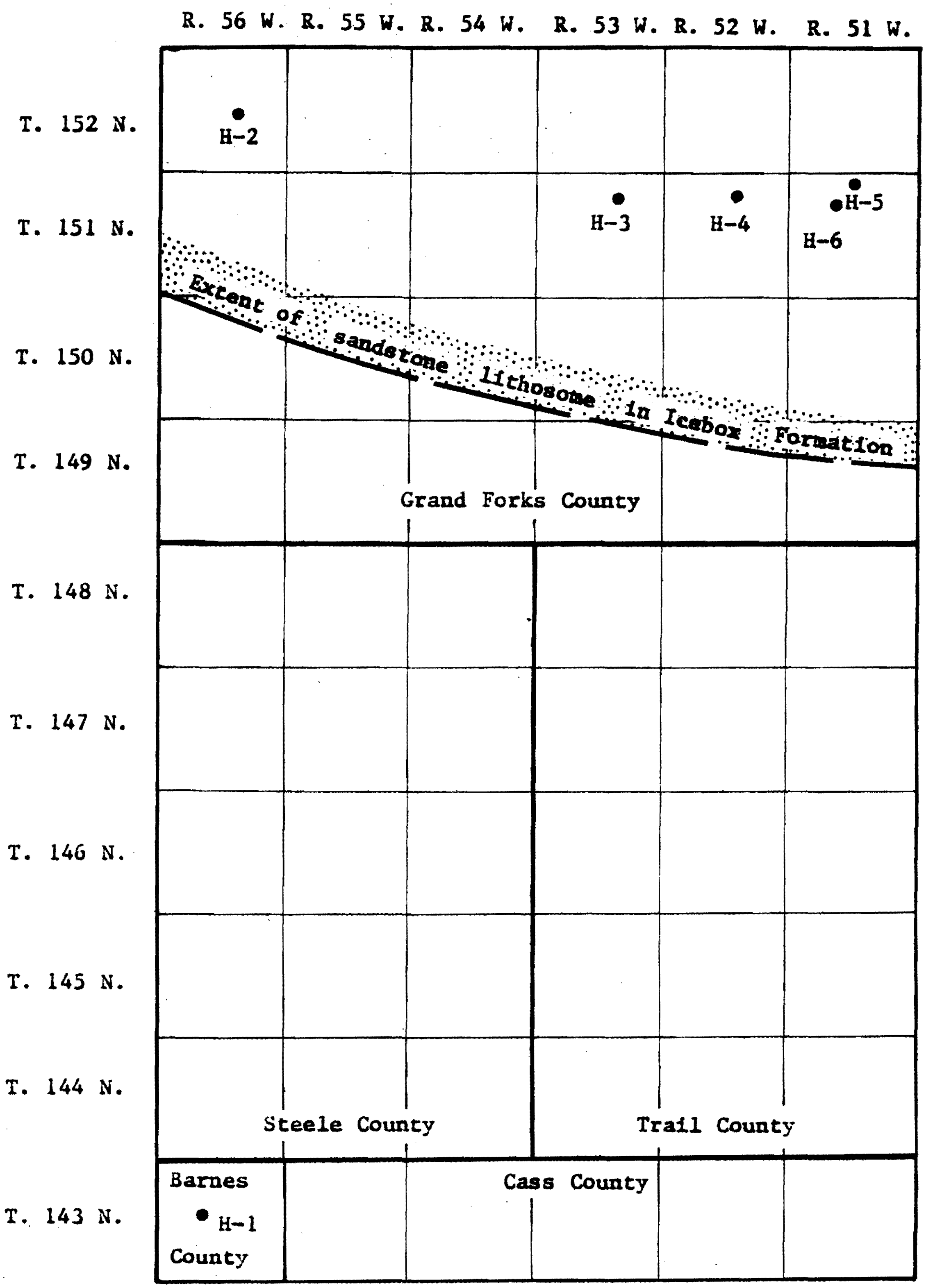
age. Most of the age determinations of the Winnipeg after 1954 have been based upon conodont studies. Holland and Waldren (1955, p. 1574) reported conodonts in the basal sandstone of the Winnipeg Formation in core from a well in Ward County, North Dakota. They said that the conodonts indicated that this sandstone was Chazyan or Blackriveran in age. Carlson (1960, p. 75) found conodonts in core from three wells located in the eastern third of North Dakota. He suggested that the Icebox might be Blackriveran to Trentonian, and the Roughlock might be Trentonian in age.

Oberg (1966, p. 136) studied conodonts of the Winnipeg at the type area at Lake Winnipeg, Manitoba. Although he found no fossils in the Black Island, conodonts from the overlying Deer Island suggested a Trentonian age for that unit.

Sweet (1982, p. 1034) studied conodonts from outcrops of the Winnipeg in the Black Hills, South Dakota. He determined the Icebox Formation to be Rocklandian and early Kirkfieldian in age and the Roughlock to be Kirkfieldian to earliest Shermanian in age. He used a faunal break as evidence for an unconformity which he interpreted as separating the Roughlock from the overlying strata of the Bighorn Group. The hiatus was said to represent much of Shermanian and early Edenian time.

In 1984 Walter C. Sweet (written communication, 1984) examined several conodont suites collected by Clarence G. Carlson in the early 1960's. These samples were from the Icebox and Roughlock Formations from cores from five stratigraphic-test holes which the Lehigh Cement Company drilled in Grand Forks and Barnes Counties, North Dakota (Fig. 8). On the basis of the conodonts examined, Walter C. Sweet (written

Figure 8. Location of Lehigh Cement Company stratigraphic-test holes in eastern North Dakota and southern extent of sandstone lithosome in the shale of the Icebox Formation.

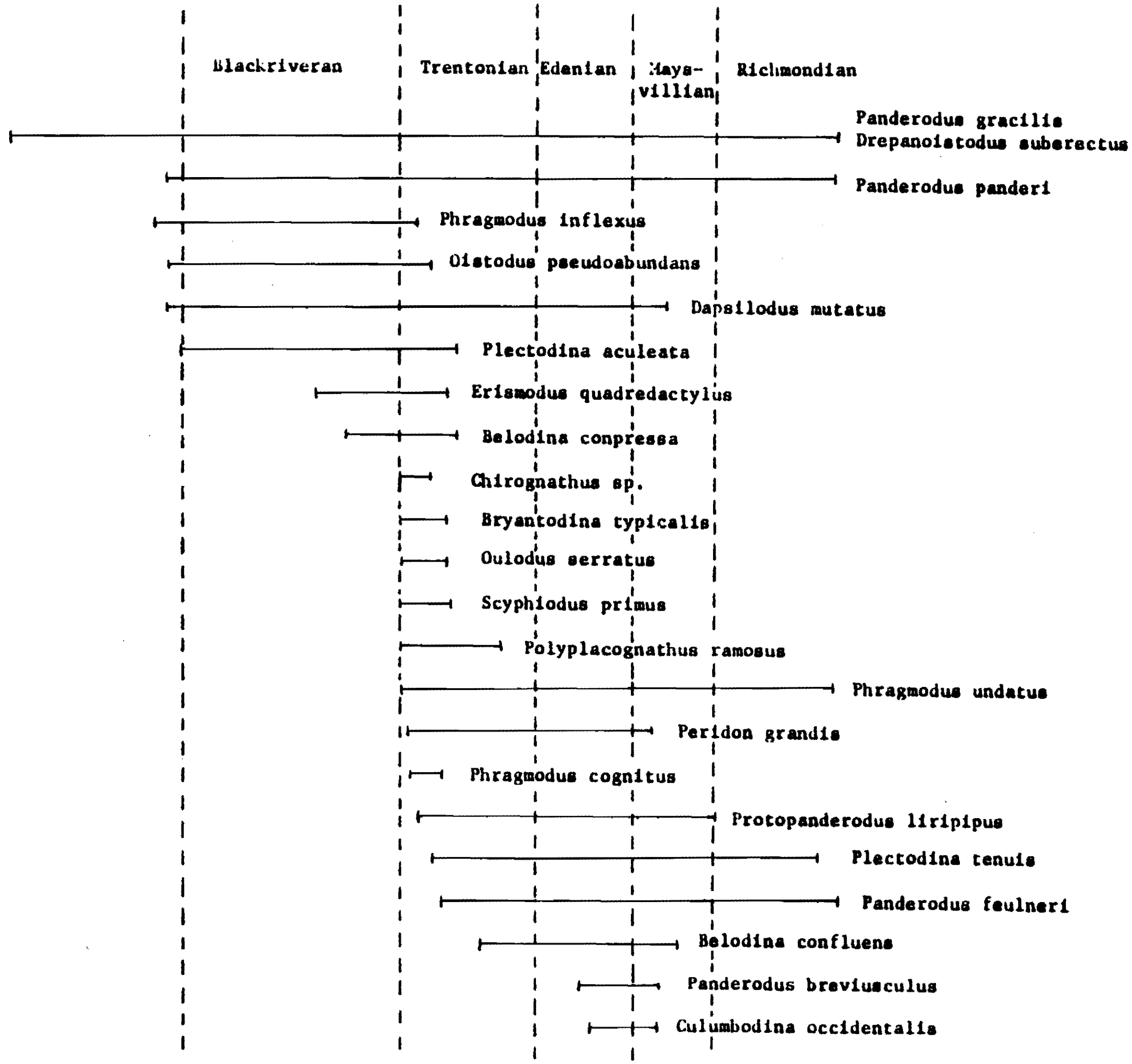

R. 56 W.
R. 55 W.
R. 54 W.
R. 53 W.
R. 52 W.
R. 51 W.
T. 152 N.
T. 151 N.
T. 150 N.
T. 149 N.
T. 148 N.
T. 147 N.
T. 146 N.
T. 145 N.
T. 144 N.
T. 143 N.
H-2
H-3
H-4
H-5
H-6
Extent of sandstone lithosome in Icebox Formation
Grand Forks County
Steele County
Trail County
Barnes County
H-1
Cass County

communication, 1984) determined the "predominantly sandy lower strata" (Icebox Formation) in eastern North Dakota to be equivalent in age ("Trenton") to the Icebox and Roughlock Formations in the Black Hills, South Dakota and determined the "shaly-carbonate upper part" (Roughlock Formation) of eastern North Dakota to be middle to late Edenian in age. Figure 9 shows the range of the conodonts found in these strata. The list of conodonts found at each well site and the depth at which they were collected is given in Appendix E. In Grand Forks County (wells H-2 through H-6), the Icebox consists mostly of shale with a sandstone body which is up to 60 feet (18 m) thick. There are also some limestone layers near the base of the cored intervals, beneath the sandstone. The Roughlock in Grand Forks County is an argillaceous limestone. In the H-1 well in Barnes County, the Icebox is composed of shale and limestone but contains no sandstone. The Roughlock in the H-1 well is composed of argillaceous limestone and calcareous shale.

Sweet recognized lower and upper conodont faunal assemblages which correspond to Icebox and Roughlock strata, respectively, in eastern North Dakota and suspected that a faunal break existed between the two assemblages. A break between the two faunal assemblages would imply that an unconformity separates the Icebox from the Roughlock in eastern North Dakota. It is perhaps significant that, in this area, unlike most other places in the state, the Icebox contains a large lithosome of sandstone (Fig. 8). It is possible that Sweet's suggested unconformity in this area is related to this sandstone body. Erosion or non-deposition may have occurred at the surface of this sandstone body, whether it was formed as an offshore bar or a shoreline deposit.

Elsewhere in the state, there is no evidence to support the

Figure 9. Range of conodonts found in six wells within Winnipeg Group strata in eastern North Dakota (After Sweet, written communication, 1984).


Blackriveran
Trentonian
Edenian
Maya-villian
Richmondian
Panderodus gracilis
Drepanoistodus suberectus
Panderodus panderi
Phragmodus inflexus
Oistodus pseudoabundans
Dapsilodus mutatus
Plectodina aculeata
Erismodus quadredactylus
Belodina conpressa
Chirognathus sp.
Bryantodina typicalis
Oulodus serratus
Scyphiodus primus
Polyplacognathus ramosus
Phragmodus undatus
Peridon grandis
Phragmodus cognitus
Protopanderodus liripipus
Plectodina tenuis
Panderodus feulneri
Belodina confluens
Panderodus breviusculus
Culumbodina occidentalis

existence of an unconformity between the Icebox and the Roughlock. The Union-Aanstad No. 1 well (NDGS Well No. 20) was cored through the Icebox-Roughlock formational boundary and the contact appears to be conformable and gradational. In the H-1 well, located in Barnes County south of the Grand Forks County sandstone lithosome (Fig. 9), five species (Phragmodus undatus, Periodon grandis, Protopanderodus liripipus, Plectodina tenuis, and Panderodus feulneri) from Sweet's upper faunal assemblage range across the Icebox-Roughlock boundary. There are no species at this location which could be used to separate Sweet's lower and upper faunal assemblage. The lack of a faunal break in the H-1 well suggests that Sweet's suggested unconformity between the Icebox and the Roughlock need not be widespread and may be confined to Grand Forks County in eastern North Dakota or that it may not exist. The type of contact is an important factor in the interpretation of the depositional history as a disconformable contact between the Icebox and Roughlock would require a vastly different explanation than that of a gradational contact. A conformable, gradational contact between the Icebox and Roughlock suggests that a facies relationship may have existed between the two formations while an unconformity between the two formations would imply an episode of erosion or nondeposition between them.

Deadwood-Black Island Boundary

General

One of the goals of this project was to reexamine the boundary between the Deadwood Formation and the Black Island Formation in North Dakota. Witzke (1980, p. 3) suggested that a prolonged period of erosion representing the late Canadian, all of the Whiterockian, and portions of the Chazyan separated the deposition of Deadwood rocks from the overlying Winnipeg. Even so, recognizing the boundary has been a continuing problem for geologists working on deep strata in the Williston Basin. Some geologists have picked the contact at the first encounter of limestone or shale beneath the Icebox Formation. Citing the difficulty in picking the boundary in South Dakota, Bolyard (1983, p. 1330) chose to call all pre-Red River strata the "Winnipeg Formation". This study has shown that the Deadwood-Black Island contact can be picked by correlating between well logs.

Interpretation

The location of the Deadwood-Black Island boundary can be best shown by use of cross sections such as those shown on Plate 1. Cross section A-A' is a stratigraphic cross section, with the top of the Roughlock Formation used as the datum, which extends from south to north through western North Dakota. Section B-B' is a similar section, but it extends from west to east through the central part of the state. Careful examination of Deadwood sections showed that beds within the Deadwood could be correlated over great distances. For example, on Section A-A', horizon A can be traced from the center of the basin, north and south, to the borders of the state. Horizons B and C can also be traced north and south, but the rocks which mark the top of these horizons have been truncated before reaching the borders of the state. As shown on Plate 1 (section A-A'), hundreds of feet of Deadwood section are removed to the north and south as compared to the center (near NDGS Well No. 2373) of the Williston Basin. Much of the truncation occurs beneath the shale and sandstone beds herein informally called the lower member of the Black Island Formation.

In previous studies (Carlson, 1960; Anderson, 1982), the boundary between the Deadwood and the Black Island was placed at the horizon marked by the dashed line on Plate 1. In this report, the dashed line separates the lower and upper members of the Black Island Formation. Placing the Deadwood-Black Island contact at the dashed line would imply that large-scale erosion had occurred within, rather than on the surface of, the Deadwood Formation. It seems more logical to place the Deadwood-Black Island contact at the level of large-scale erosion marked on Plate 1 as an unconformity. The shale and sandstone beds directly above the Deadwood-Black Island contact, as defined here, are recognized for the first time, in this study, as being part of the Black Island Formation and included in the Winnipeg Group.

Methods

The primary source of data for this study was well log files maintained by the North Dakota Geological Survey and cores housed in the Wilson M. Laird Core and Sample Library on the University of North Dakota campus. Cores from thirteen wells were chosen for wide geographic distribution (Fig. 10) and stratigraphic variation of cored interval. Core descriptions (Appendix D) were made using a hand lens and a binocular microscope. The rock color chart (Goddard and others, 1948) was used as a standard for color descriptions. Thin sections were examined using reflecting light and polarizing microscopes. Sandstones were classified according to the scheme of Gilbert (Williams and others, 1954, p. 292-293), shales were named using the classification of Potter and others (1980, p. 14), and carbonates were classified according to Folk (1959).

Approximately 300 well logs were studied (Fig. 11) (Appendix A) and the tops and thicknesses of the Deadwood Formation, lower and upper members of the Black Island Formation, and the Icebox and Roughlock Formations were recorded (Appendices B and C). Using the thickness data, isopach maps were constructed for each of the units.

Typical gamma ray and resistivity log responses for the Winnipeg in the Williston Basin are given on Figure 12. Comparison of cores to the corresponding section of the well log indicated that lithology had been consistently and accurately interpreted from well log responses. Thus, considerable confidence was developed that regional, lithologic interpretations and lithologic correlations could be fairly made on the basis of correlation from well to well by the use of well logs.

Figure 10. Location of wells from which cores were examined during this study.

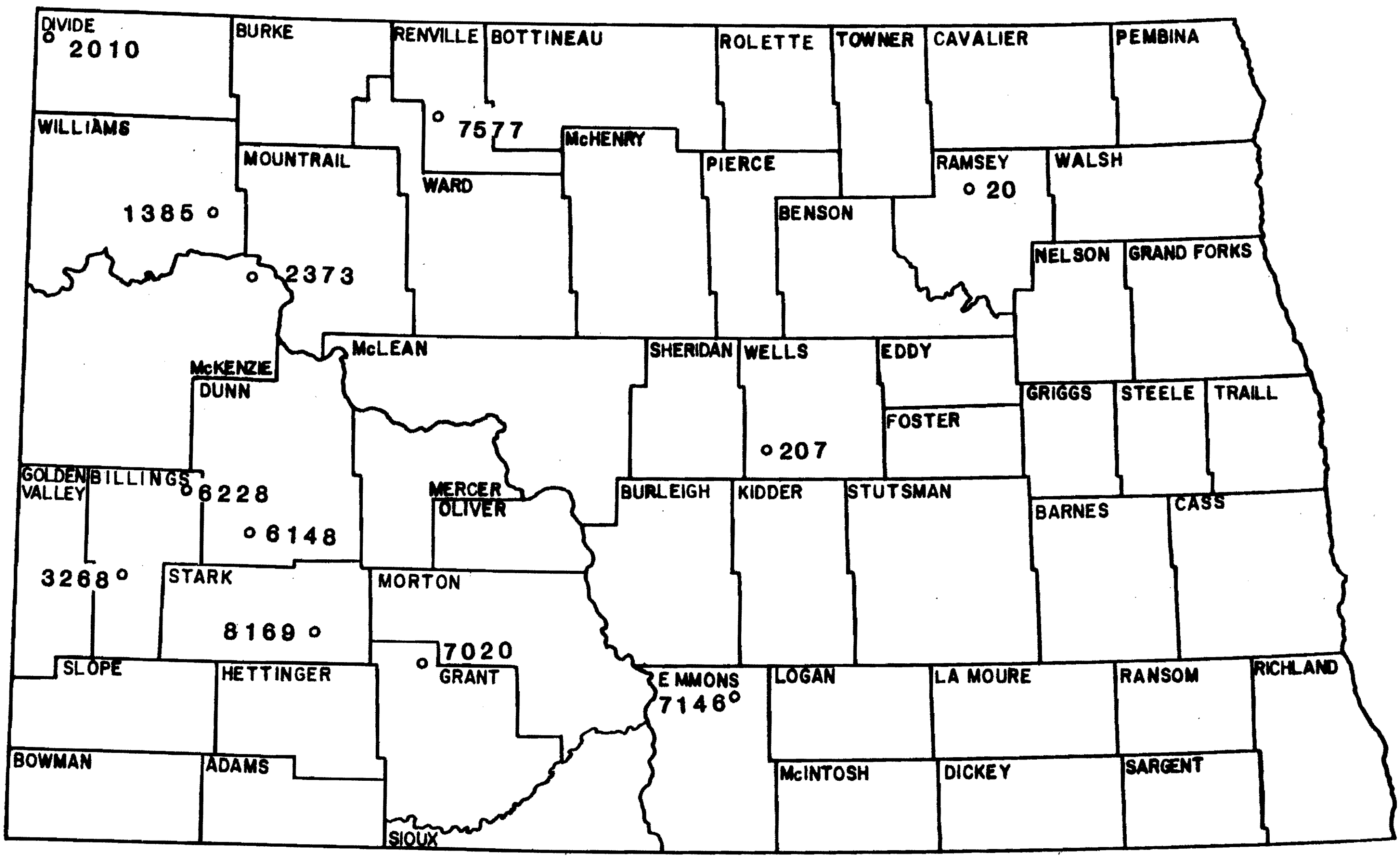

DIVIDE
2010
BURKE
RENVILLE
BOTTINEAU
ROLETTE
TOWNER
CAVALIER
PEMBINA
WILLIAMS
7577
McHENRY
MOUNTRAIL
PIERCE
RAMSEY
WALSH
WARD
20
1385
BENSON
NELSON
GRAND FORKS
2373
McLEAN
SHERIDAN
WELLS
EDDY
McKENZIE
DUNN
GRIGGS
STEELE
TRAILL
FOSTER
207
GOLDEN VALLEY
BILLINGS
6228
MERCER
OLIVER
BURLEIGH
KIDDER
STUTSMAN
BARNES
CASS
6148
3268
STARK
MORTON
8169
7020
SLOPE
HETTINGER
GRANT
EMMONS
7146
LOGAN
LA MOURE
RANSOM
RICHLAND
BOWMAN
ADAMS
McINTOSH
DICKEY
SARGENT
SIOUX

Figure 11. Location of wells from which well logs were examined during this study.

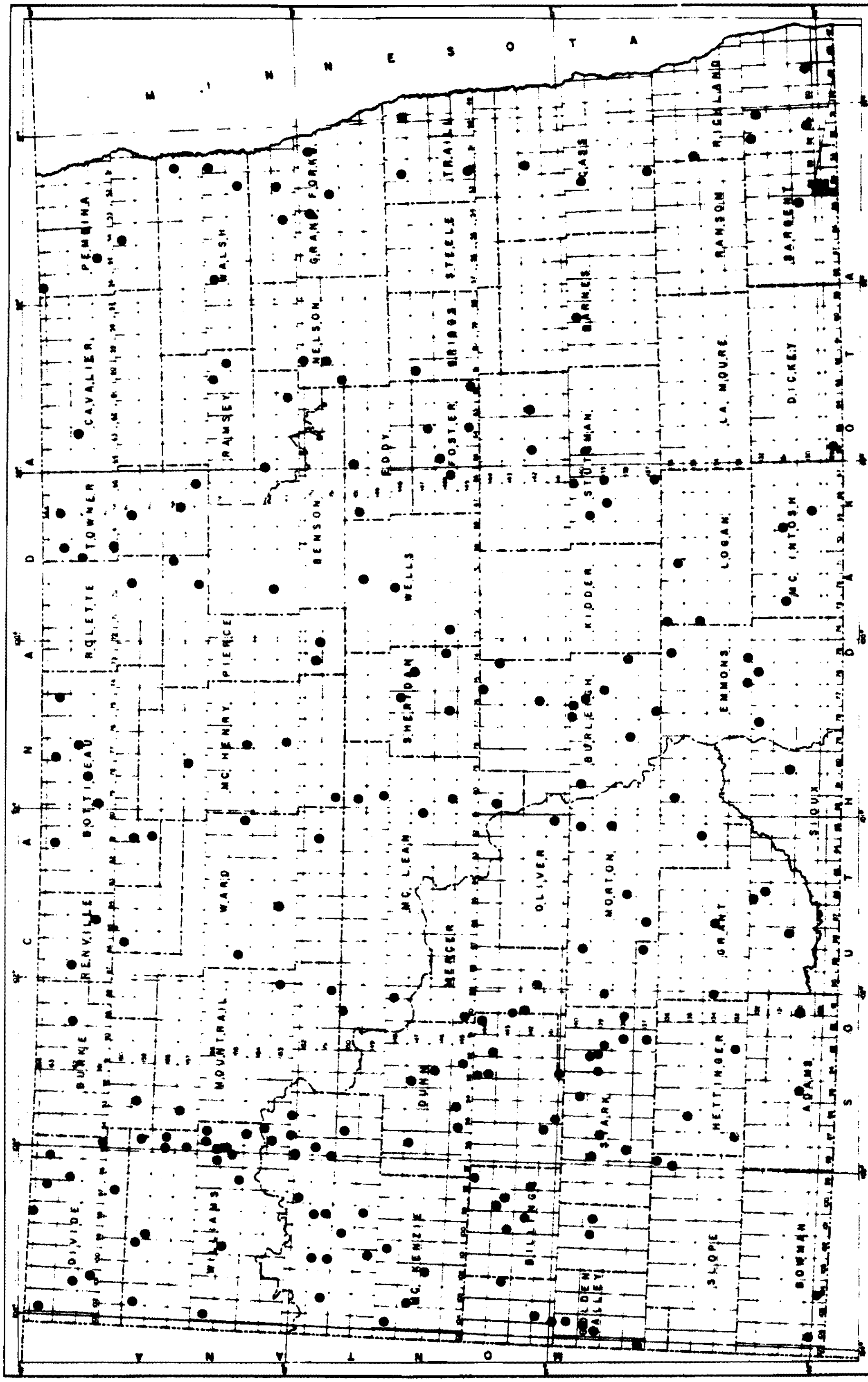
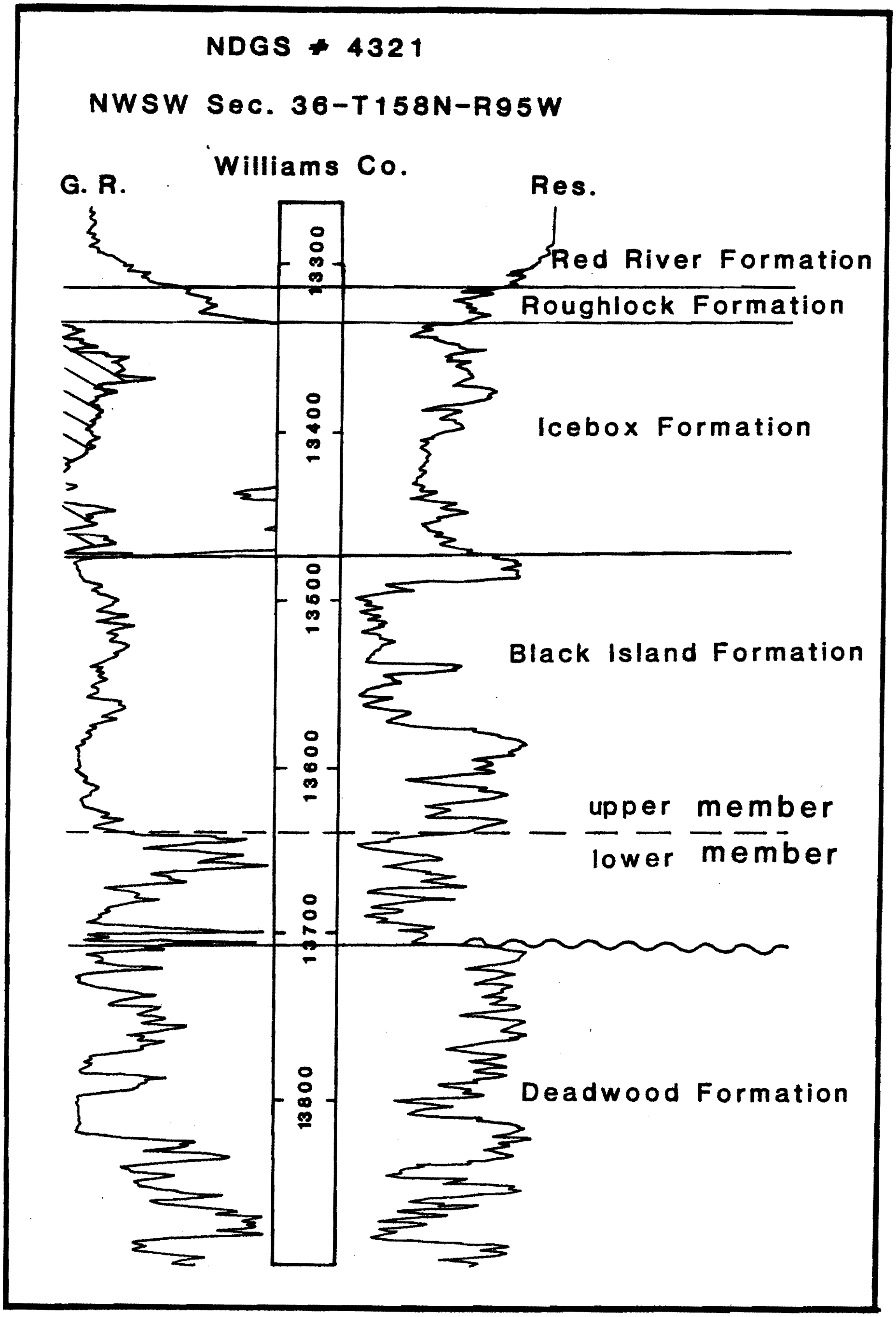

MINNESOTA
CANADA
MONTANA
SOUTH DAKOTA
NORTH DAKOTA
PEMBINA
CAVALIER
TOWNER
ROLETTE
BOTTINEAU
RENVILLE
BURKE
DIVIDE
WILLIAMS
MOUNTRAIL
WARD
MC HENRY
PIERCE
BENSON
RAMSEY
WALSH
GRAND FORKS
NELSON
EDDY
WELLS
SHERIDAN
MC LEAN
MC KENZIE
DUNN
MERCER
OLIVER
BILLINGS
GOLDEN VALLEY
STARK
MORTON
BURLEIGH
KIDDER
STUTSMAN
FOSTER
GRIGGS
STEELE
TRAILL
CASS
BARNES
LA MOURE
DICKEY
SARGENT
RANSOM
RICHLAND
LOGAN
MC INTOSH
EMMONS
SIOUX
GRANT
HETTINGER
ADAMS
SLOPE
BOWMAN

Figure 12. Sample well log response of the Winnipeg Group from the Amerada Oil Company - N. D. "C" No. 9 (NDGS Well No. 4321), NW1/4 SW1/4 sec. 36, T. 158 N., R. 95 W., Williams County, North Dakota.



NDGS # 4321
NWSW Sec. 36-T158N-R95W
Williams Co.
G. R.
Res.
13300
13400
13500
13600
13700
13800
Red River Formation
Roughlock Formation
Icebox Formation
Black Island Formation
upper member
lower member
Deadwood Formation

LITHOLOGIC DESCRIPTIONS

Introduction

On the basis of core descriptions and interpretations from well log responses, the Winnipeg Group in North Dakota can be broken into four lithostratigraphic units: lower and upper members of the Black Island Formation, the Icebox Formation and the Roughlock Formation. All of these lithostratigraphic units are not always present at any given location. For example, the lower member of the Black Island is thickest in the western part of the state and is absent in the eastern part, and the Roughlock Formation thins to a feather edge in the west and is thickest in far eastern of North Dakota.

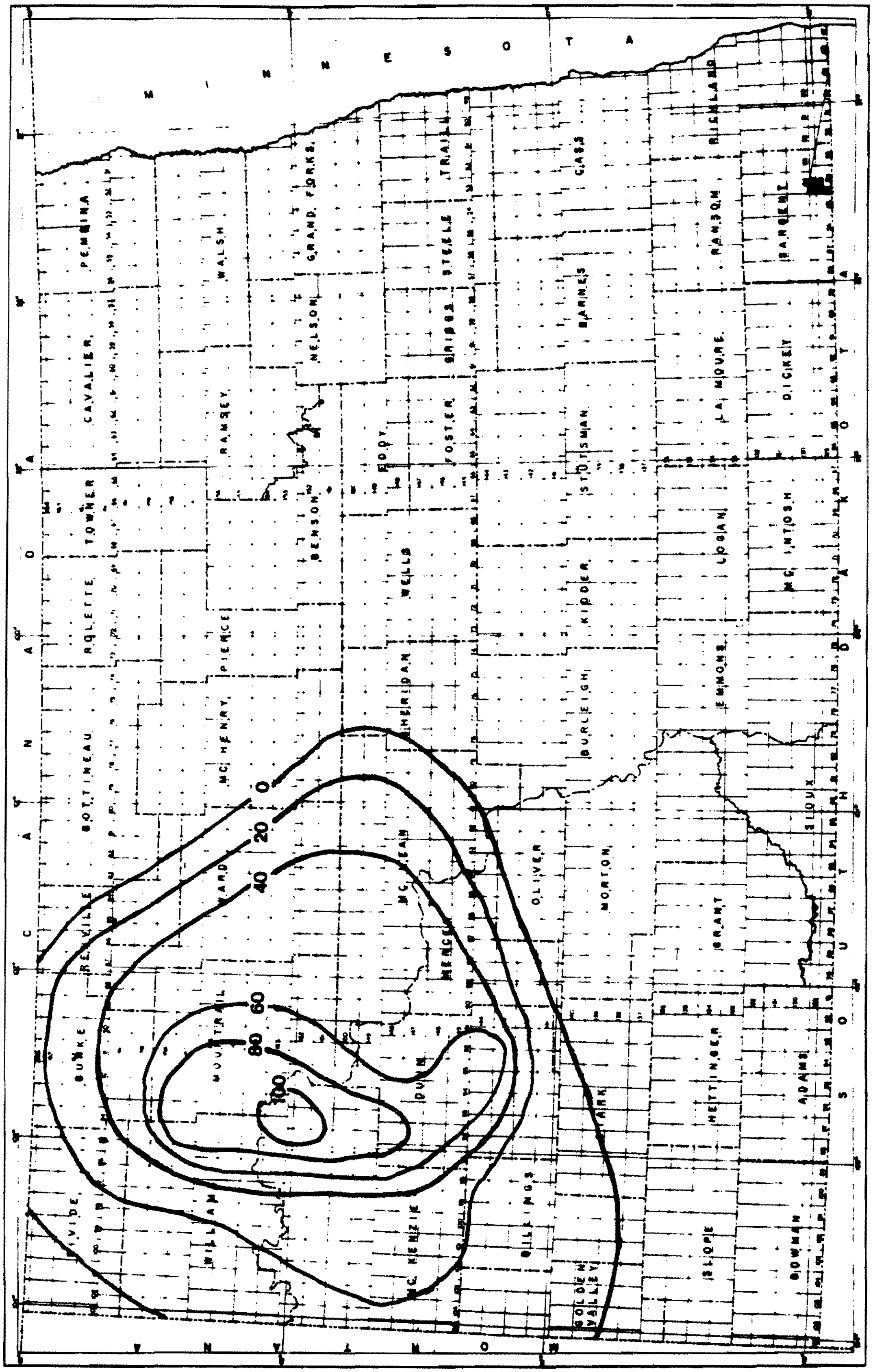
In this study, both members of the Black Island Formation have been subdivided into two lithofacies each. As used in this study, a lithofacies is a related assemblage of rocks or lithotypes. Because both the Icebox and Roughlock are relatively uniform in composition, it was not necessary to subdivide them into smaller lithologic units

Lower Member of the Black Island Formation

General

The lower member of the Black Island Formation disconformably overlies the limestone, shale, and sandstone of the Deadwood Formation and conformably underlies the sandstone of the upper member of the Black Island Formation. As shown by the isopach map (Fig. 13), the lower member of the Black Island is located almost entirely in the western half of North Dakota. It thickens to more than 100 feet (30 m) along a

Figure 13. Isopach map of the lower member of the Black Island Formation. Contour interval is 20 feet (6 m).


NORTH DAKOTA
0
20
40
60
80
100
PEMBINA
CAVALIER
TOWNER
ROLETTE
BOTTINEAU
RENVILLE
BURKE
DIVIDE
WILLIAMS
MOUNTRAIL
WARD
MC HENRY
PIERCE
RAMSEY
WALSH
GRAND FORKS
NELSON
BENSON
EDDY
WELLS
SHERIDAN
MC LEAN
MERCER
DUNN
MC KENZIE
BILLINGS
GOLDEN VALLEY
STARK
OLIVER
MORTON
BURLEIGH
KIDDER
STUTSMAN
FOSTER
GRIGGS
STEELE
TRAILL
CASS
BARNES
RANSOM
RICHLAND
SARGENT
DICKEY
LA MOURE
LOGAN
MC INTOSH
EMMONS
SIOUX
GRANT
HETTINGER
ADAMS
SLOPE
BOWMAN

north-south trend in the area of the present-day Nesson Anticline. The overall pattern of the isopach contours is circular, although a thickening trend extends eastward toward the center of the state (into McHenry and Sheridan Counties).

This study recognizes two lithofacies within the lower member of the Black Island Formation: a red-bed lithofacies and a green quartz wacke lithofacies. The red-bed lithofacies consists of dark reddish brown sandstone and clayshale, while the green quartz wacke lithofacies is, as its label suggests, composed mostly of a light greenish gray, quartz wacke. The lower member of the Black Island Formation has been cored at only three locations: two in the central-basin area, in Williams and McKenzie Counties, and another in southern Billings County where the member is very thin.

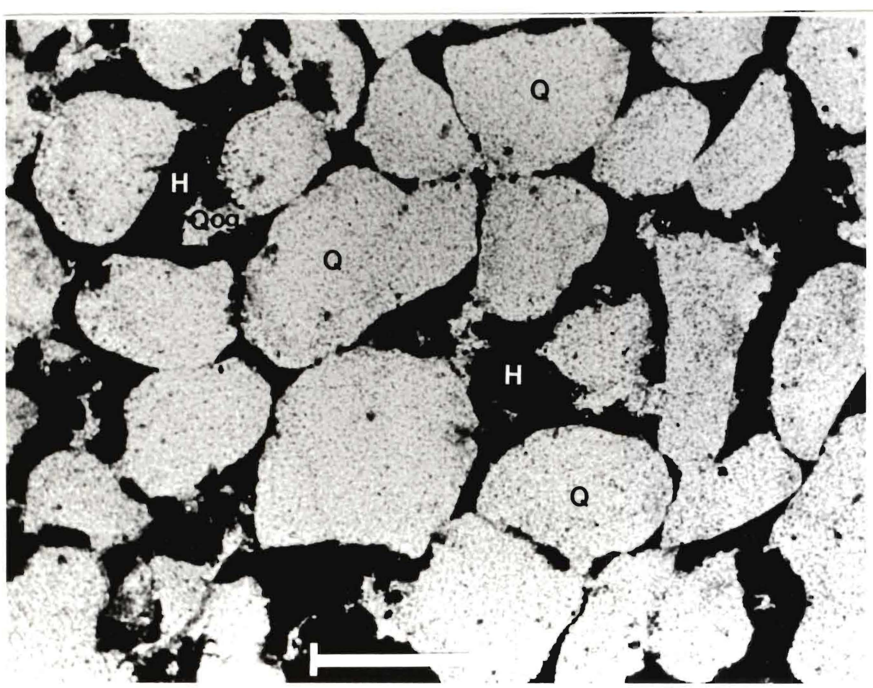
Red-bed Lithofacies

A dark reddish brown, quartz arenite lithotype is a major constituent of the red-bed lithofacies. The dark reddish brown, quartz arenite is commonly fine- to medium-grained, well-sorted, and well-rounded (Fig. 14). Pervasive hematite cement gives this lithotype its distinctive red color, although some quartz cement and clay matrix may also be present (Fig. 15). The reddish brown, quartz arenite is finely laminated in some places; although it is more commonly structureless, it is usually well indurated but becomes friable with an increase in the content of interstitial clay. The reddish brown, quartz arenite is not bioturbated and no fossils were observed within it. This lithotype is of variable thickness with beds ranging from about 20 feet (6 m) to one foot (30 cm) in thickness. The reddish brown, quartz arenite lithotype is, in places, interlaminated with lesser amounts of reddish brown

Figure 14. Core slab of dark reddish brown quartz arenite from red-bed lithofacies (lower member, Black Island Formation). NDGS Well No. 2373, McKenzie County, 14,196 feet.

Figure 15. Photomicrograph of dark reddish brown quartz arenite from red-bed lithofacies (lower member, Black Island Formation). Hematite cement (H) has replaced much of the quartz cement (Qog). (Quartz grain - Q). NDGS Well No. 3268, Billings County, 12,627 feet. Bar equals 0.5 mm.


1 CM


Q
H
Qog
Q
H
Q

mudstone or white quartz arenite. The reddish brown, quartz arenite lithotype may rest upon, or may underlie, either a red clayshale lithotype or rocks of the green, quartz wacke lithofacies.

The other important lithology of the red-bed lithofacies is a red clayshale lithotype. The red clayshale lithotype is characterized by a sequence of dark red clayshales (Fig. 16) and interbedded dark red and dark green clayshales. These clayshales are often finely laminated (1-3 mm) and are in places interlaminated with thin lenses of sandstone or mudstone. Figure 17 shows a fine-grained, cross-laminated sandstone found within this lithotype and Figure 18 shows interlaminated sandstone and clayshale. The red clayshale lithotype also contains mud cracks (Fig. 19) and red siltstone with horizontal laminations (Fig. 20). As in the red quartz arenite lithotype, bioturbation is absent, and no fossils were observed. The red clayshale lithotype ranges from 5 to 10 feet (1.5 to 3 m) in thickness. In NDGS Well No. 1385, in Williams County, the red clayshale lithotype directly overlies the Deadwood Formation but elsewhere is not stratigraphically restricted to the basal part of the lower member of the Black Island Formation. It is often interbedded with the red quartz arenite lithotype higher in the section of the lower member of the Black Island. The red-bed lithofacies contains both fining-upward and coarsening-upward sequences.

Green Quartz Wacke Lithofacies

The green quartz wacke lithofacies is characterized by poorly sorted, well-rounded, fine- to coarse-grained, light greenish gray, argillaceous, quartz wacke (Fig. 21). Montmorillonite and other, unidentified clay minerals are interstitial between the sandstone grains and give this lithotype its light greenish gray color. In places, thin

Figure 16. Core slab of reddish brown clayshale from red-bed lithofacies (lower member, Black Island Formation). NDGS Well No. 2373, McKenzie County, 14,150 feet.

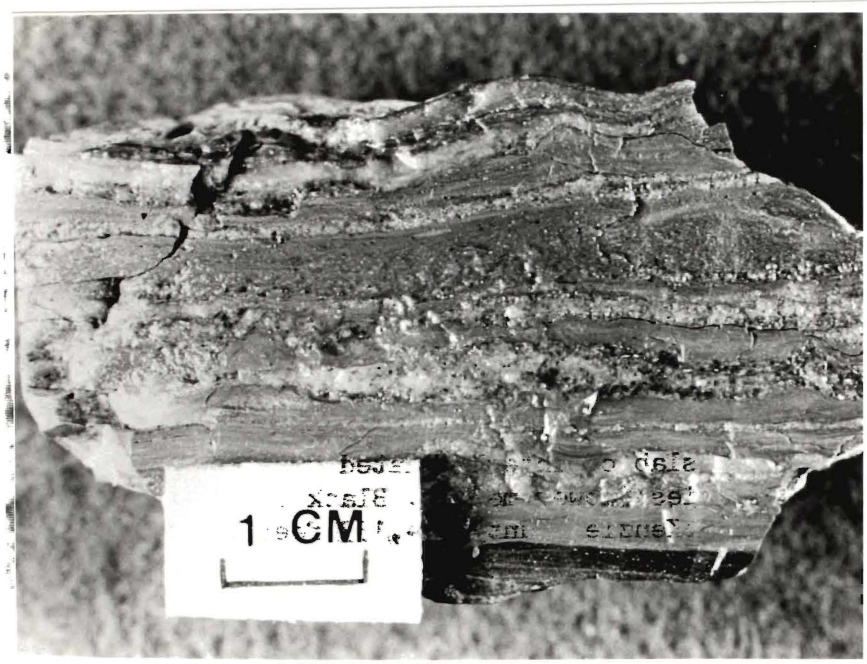
Figure 17. Core slab of cross-laminated sandstone from red-bed lithofacies (lower member, Black Island Formation). NDGS Well No. 2373, McKenzie County, 14,208 feet.


1 CM


1 CM

Figure 18. Core slab of interlaminated sandstone and shale from red-bed lithofacies (lower member, Black Island Formation). NDGS Well No. 2373, McKenzie County, 14,153 feet.

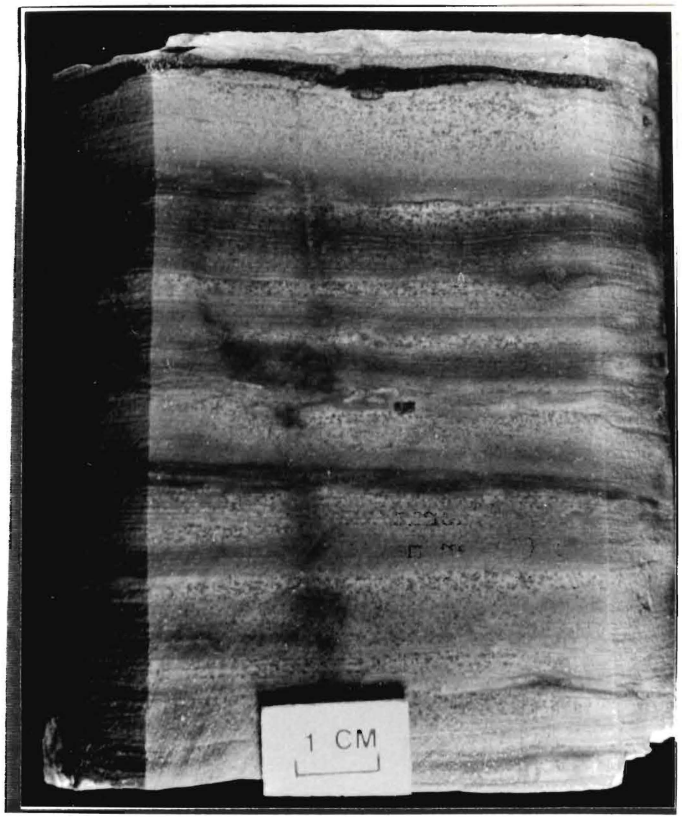
Figure 19. Core slab of red clayshale from red-bed lithofacies with mud cracks (lower member, Black Island Formation). NDGS Well No. 1385, Williams County, 14,159 feet.

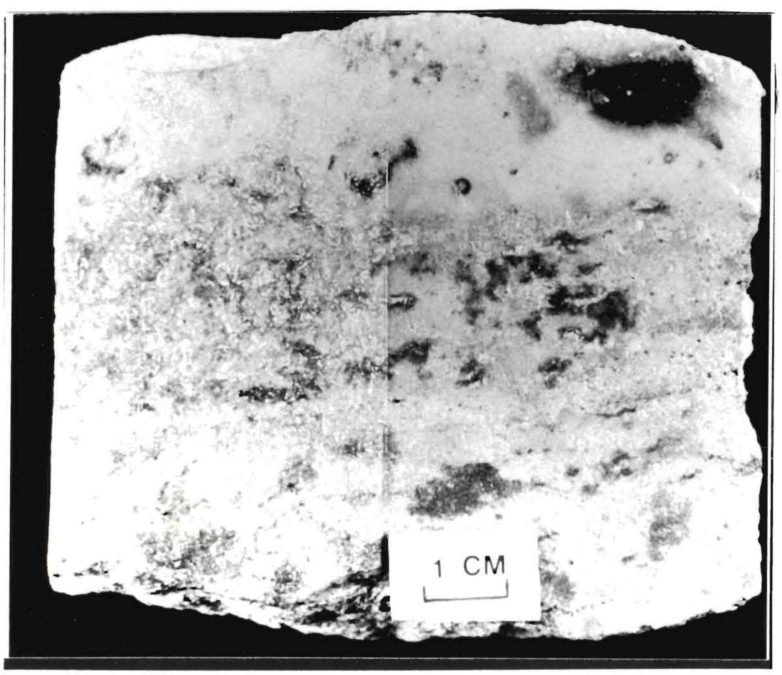

1 CM


1 CM

Figure 20. Core slab of horizontally laminated red siltstone from red-bed lithofacies (lower member, Black Island Formation). NDGS Well No. 1385, Williams County, 14,163 feet.

Figure 21. Core slab of green quartz wacke lithofacies (lower member, Black Island Formation). NDGS Well No. 1385, Williams County, 14,129 feet.


1 CM


1 CM

lenses of light green clayshale alternate with layers of a well-indurated quartz arenite or quartz wacke. In some places, strata of the green quartz wacke lithofacies are very friable. Increased friability appears to be related to an increase in interstitial clay. Phosphate nodules also occur within this sandstone.

Upper Member of the Black Island Formation

General

The upper member of the Black Island Formation is composed primarily of sandstone. It is conformably underlain by the lower member of the Black Island and conformably overlain by the clayshale of the Icebox Formation. As shown in the isopach map (Fig. 22), this member is present over a large portion of North Dakota. It reaches a maximum thickness of more than 160 feet (50 m) in northwestern North Dakota in the area of the Nesson Anticline. The isopach contours of this member show a concentric pattern around the thickest section. The upper member of the Black Island thins rapidly east and south from the thickest section and thins to a feather edge along the southern border of North Dakota (Fig. 22). In much of eastern North Dakota, the upper member of the Black Island is absent or, where present, ranges up to 15 feet (4.6 m) in thickness. This study recognizes two lithofacies within the upper member of the Black Island Formation: a quartz arenite lithofacies, and a green quartz wacke lithofacies.

Quartz Arenite Lithofacies

The quartz arenite lithofacies is dominated by, and named for, a well-sorted, fine- to medium-grained, well-rounded, quartz-cemented,

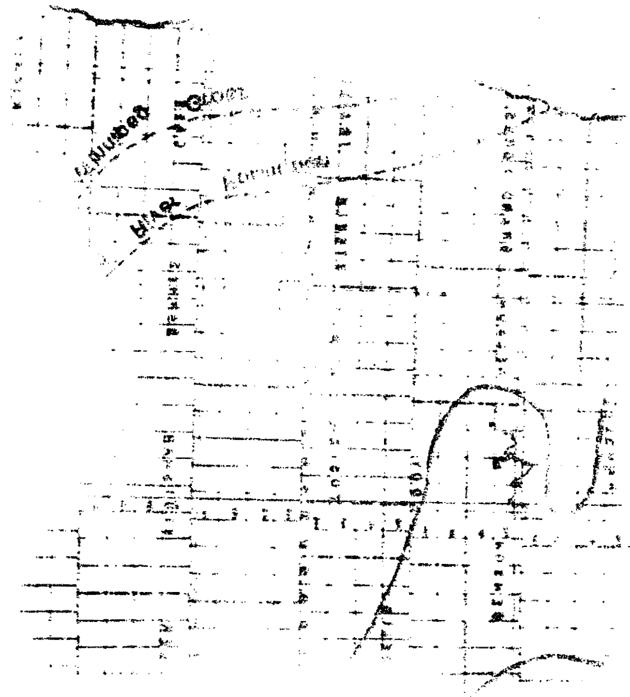
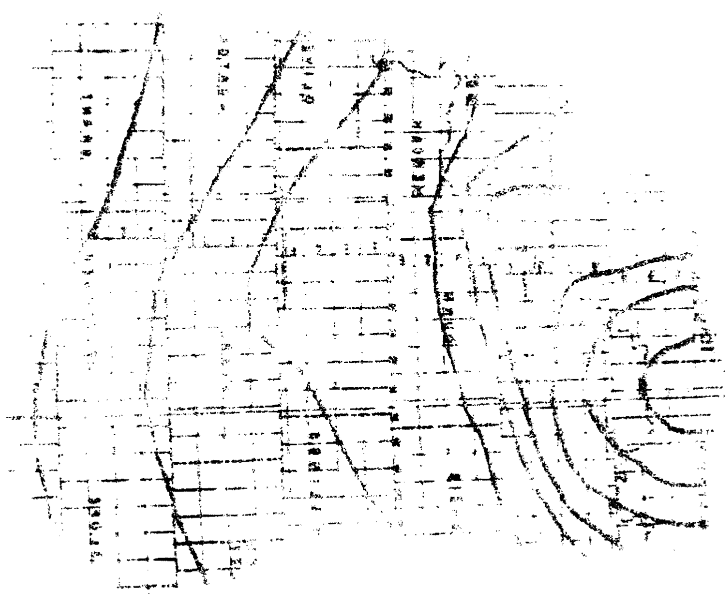
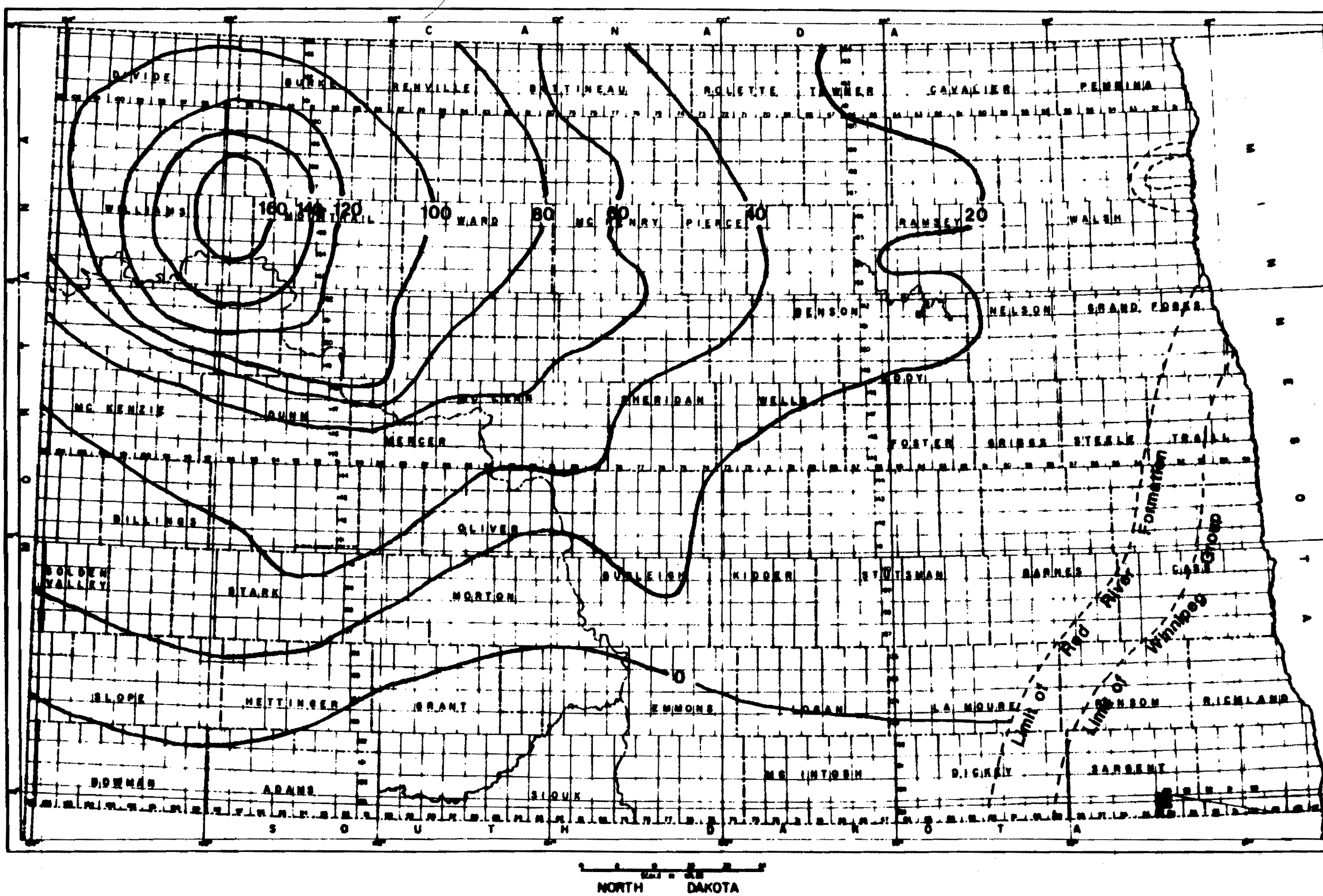


Figure 22. Isopach map of the upper member of the Black Island Formation. The contour interval is 20 feet (6 m). The upper member of the Black Island section between the dashed lines in eastern North Dakota may be incomplete due to post-Ordovician erosion.




CANADA
SOUTH DAKOTA
MINNESOTA
MONTANA
DIVIDE
BURKE
RENVILLE
BOTTINEAU
ROLETTE
TOWNER
CAVALIER
PEMBINA
WILLIAMS
MOUNTRAIL
WARD
MC HENRY
PIERCE
RAMSEY
WALSH
BENSON
NELSON
GRAND FORKS
EDDY
MC KENZIE
DUNN
MC LEAN
SHERIDAN
WELLS
MERCER
FOSTER
GRIGGS
STEELE
TRAILL
BILLINGS
OLIVER
GOLDEN VALLEY
STARK
MORTON
BURLEIGH
KIDDER
STUTSMAN
BARNES
CASS
SLOPE
HETTINGER
GRANT
EMMONS
LOGAN
LA MOURE
RANSOM
RICHLAND
BOWMAN
ADAMS
SIOUX
MC INTOSH
DICKEY
SARGENT
0
20
40
60
80
100
120
140
160
Limit of Red River Formation
Limit of Winnipeg Group
NORTH DAKOTA

structureless quartz arenite (Fig 23). The other important lithotype of the quartz arenite lithofacies is a medium to dark gray, fine- to medium-grained, rounded to well-rounded, bioturbated, quartz wacke (Fig. 24). The structureless quartz arenite lithotype is irregularly interbedded with the bioturbated, quartz wacke lithotype and vertical changes between the two lithotypes are usually gradational. Stylolites are scattered throughout the rocks of the quartz arenite lithofacies although they seem to be mostly confined to those portions which contain little interstitial clay; they are more common in the quartz arenite than in the quartz wacke. Few fossils were observed within this lithofacies, although Holland and Waldren (1955) reported conodonts in what was probably this lithofacies.

Green Quartz Wacke Lithofacies

The green quartz wacke lithofacies contains just one lithotype, a green quartz wacke. The green quartz wacke is a friable to moderately indurated, light greenish gray, fine- to medium-grained, quartz wacke (Fig. 25). This lithotype is similar in texture and color to the green quartz wacke lithotype of the lower member of the Black Island. The lithotype is both underlain and overlain by rocks of the quartz arenite lithofacies. The green quartz wacke often has a gradational contact with the underlying rocks, and usually has a sharp upper contact with the rocks that overlie it. Figure 26 shows a photomicrograph of the green quartz wacke lithotype from the same sample as is shown in Figure 25. The interstitial clay matrix of the rocks of this lithotype is composed of montmorillonite and assemblages of unidentified clay minerals.

Figure 23. Core slab of quartz arenite from quartz arenite lithofacies (upper member, Black Island Formation). NDGS Well No. 2373, McKenzie County, 14,075 feet.

Figure 24. Core slab of bioturbated sandstone from quartz arenite lithofacies (upper member, Black Island). NDGS Well No. 2373, McKenzie County, 14,112 feet.

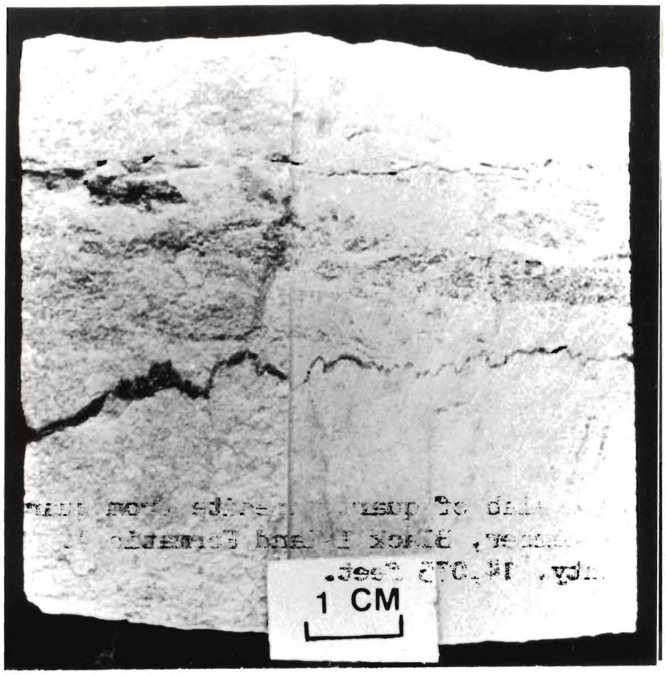

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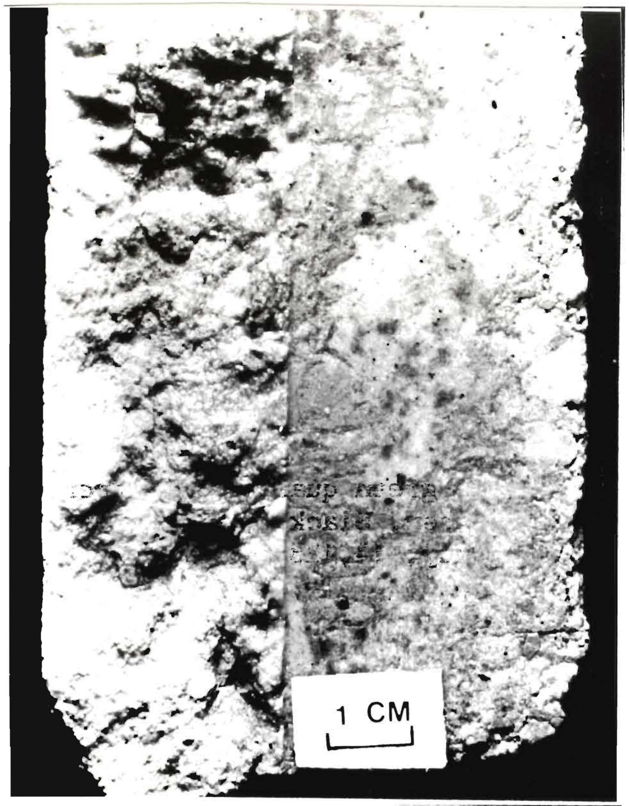
Figure 25. Core slab of green quartz wacke from green quartz wacke lithofacies (upper member, Black Island Formation). NDGS Well No. 2373, McKenzie County, 14,128 feet.

Figure 26. Photomicrograph of thin section of quartz wacke from core slab shown above (upper member Black Island Formation). (Quartz grain - Q, clay matrix - Cl). NDGS Well No. 2373, McKenzie County, 14,128 feet. Bar equals 0.5 mm.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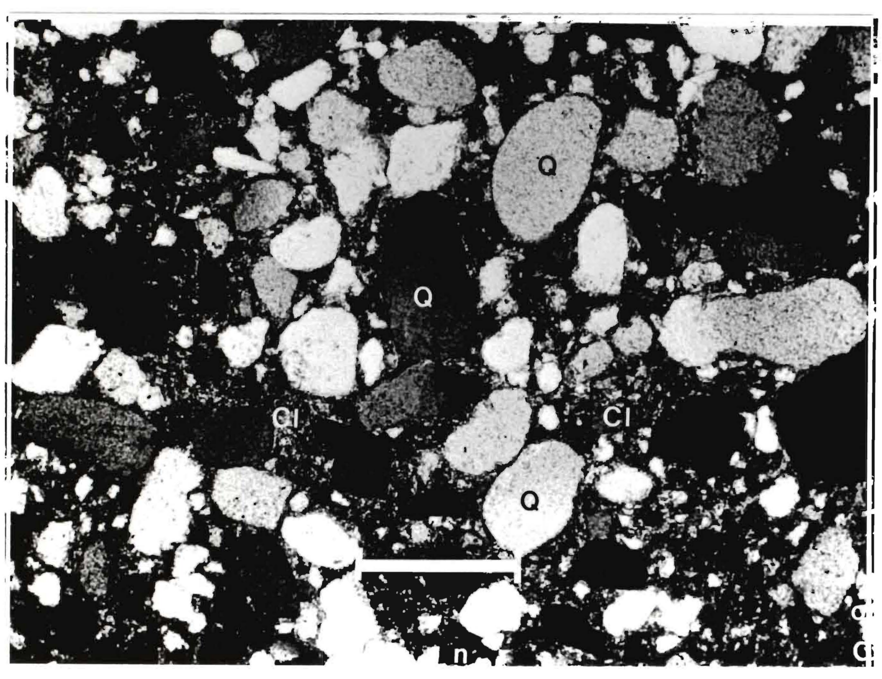

Q
Q
Cl
Cl
Q

Icebox Formation

The Icebox Formation is composed primarily of greenish gray clayshale. It has conformable, gradational contacts with both the sandstone of the underlying Black Island Formation and with the overlying argillaceous limestone of the Roughlock Formation. Except for extreme eastern North Dakota, where post-Red River erosion has removed Winnipeg strata, the Icebox is present over the whole state. As shown by the isopach map, Figure 27, the Icebox is up to 160 feet (49 m) thick in Grand Forks County and more than 150 feet (46 m) thick in the central basin area of northwestern North Dakota. A thinner zone (Fig. 27) of less than 120 feet (37 m) in thickness extends north-south between the areas of greater thickness, mentioned above. The dashed line labeled the "limit of Red River Formation" on Figure 27 shows the eastern extent of the Red River, which was truncated by post-Ordovician erosion. East of this line and west of the the line labeled "limit of Winnipeg Group", Winnipeg strata has been, at least partially, eroded.

Much of the clayshale of the Icebox Formation is dark greenish gray to dark bluish gray in color, is often bioturbated, and in some places, contains distinct worm burrows (Fig. 28). Portions of the greenish gray clayshale lithotype are fossiliferous and contain brachiopods (Fig. 29), trilobite fragments, and other, unidentified fossil fragments. This lithotype of the Icebox in places contains black phosphate nodules, as well as slickensides. Cored samples of this clayshale tend to have platy partings and disaggregate easily with the introduction of water.

Sandstone is present in the Icebox Formation in two sandstone bodies that have been cored, one in Divide County, and the other in Grand Forks County, and a third uncored body in southwestern North

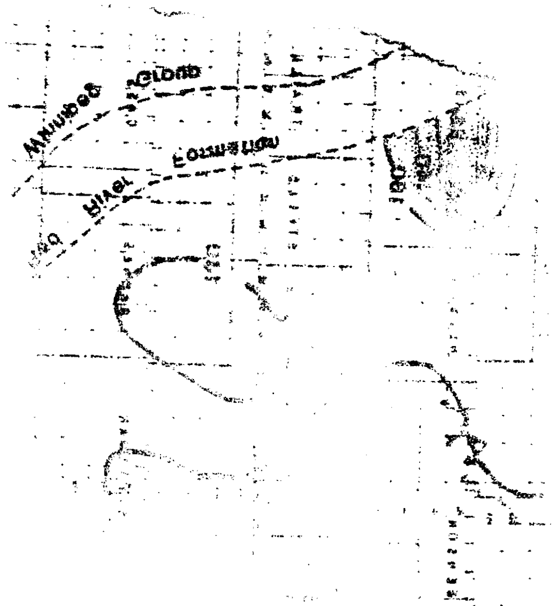
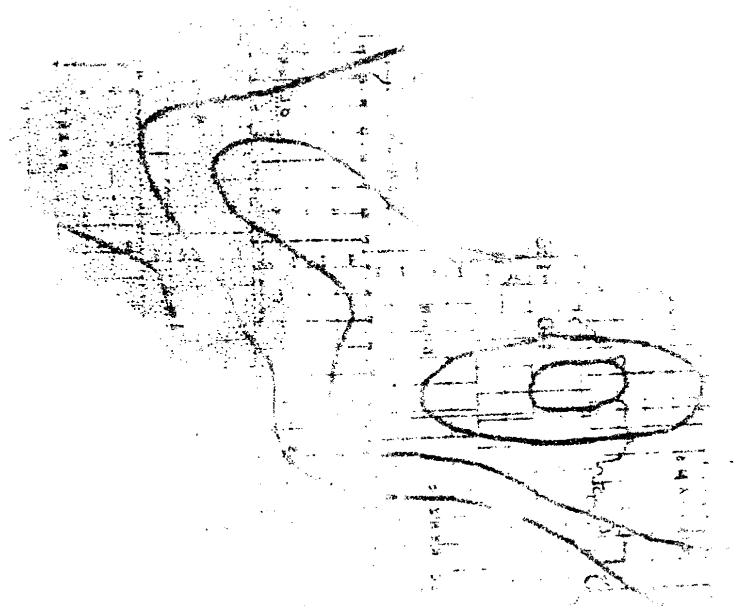


Figure 27. Isopach map of the Icebox Formation in North Dakota. The contour interval is 10 feet (3 m). The Icebox section between the dashed lines in eastern North Dakota may be incomplete due to post-Ordovician erosion.



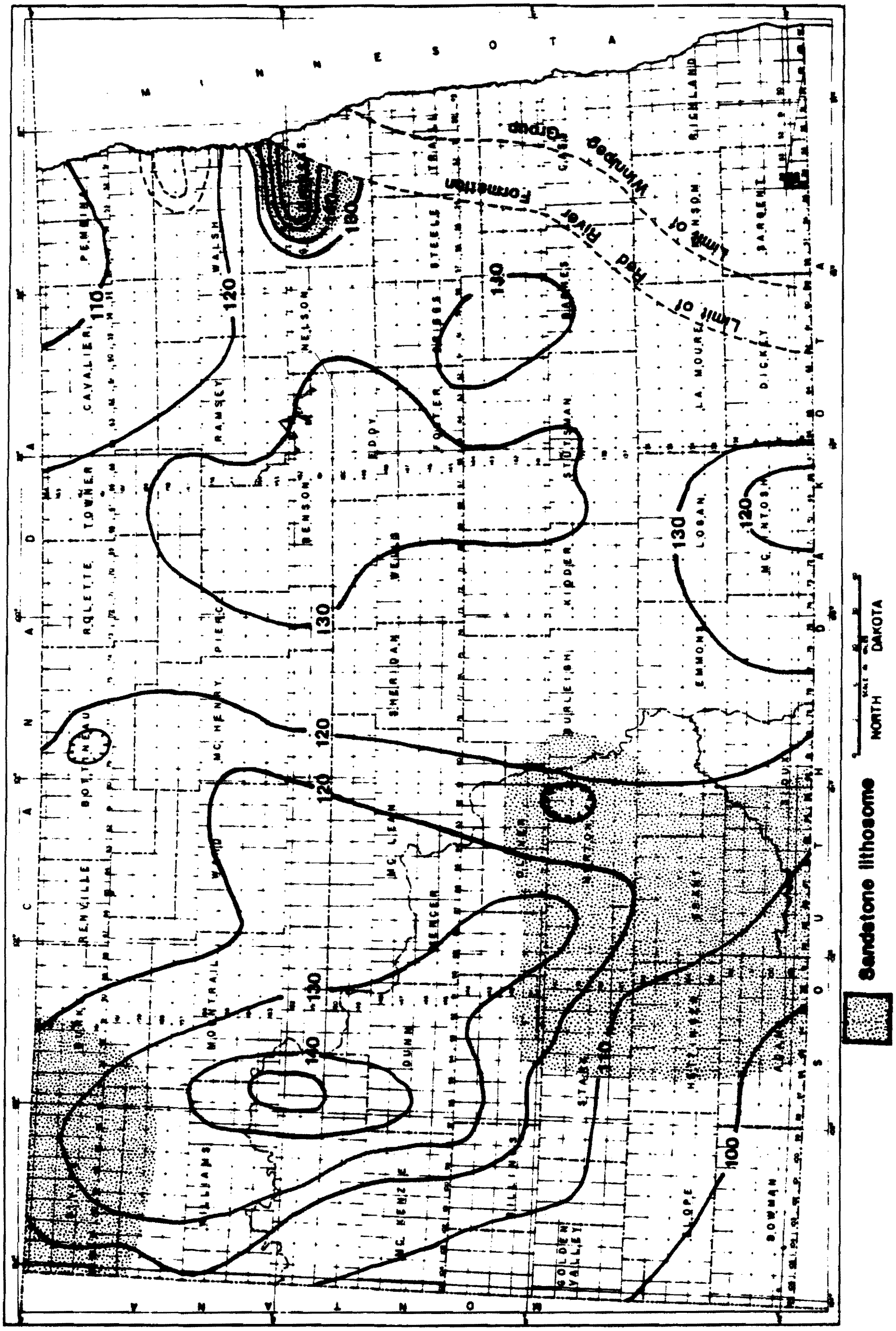
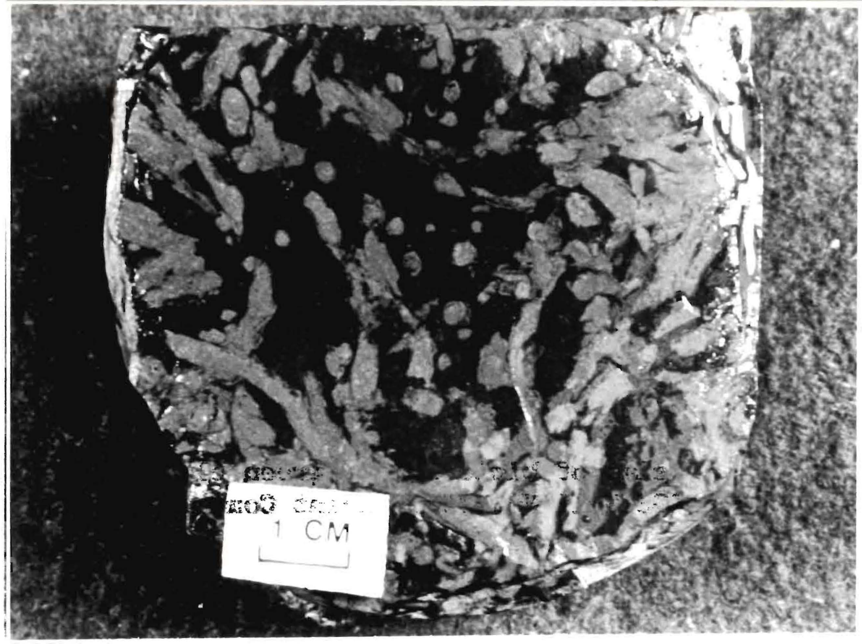

Sandstone lithosome
NORTH DAKOTA
CANADA
MINNESOTA
SOUTH DAKOTA
Limit of Winnipeg Group
Limit of Red River Formation
110
120
130
140
100
PEMBINA
CAVALIER
TOWNER
ROLETTE
BOTTINEAU
RENVILLE
BURKE
DIVIDE
WALSH
RAMSEY
BENSON
PIERCE
MC HENRY
WARD
MOUNTRAIL
WILLIAMS
NELSON
EDDY
WELLS
SHERIDAN
MC LEAN
MERCER
DUNN
MC KENZIE
GRIGGS
FOSTER
STEELE
TRAILL
CASS
BARNES
STUTSMAN
KIDDER
BURLEIGH
OLIVER
MORTON
STARK
BILLINGS
GOLDEN VALLEY
SLOPE
BOWMAN
ADAMS
HETTINGER
GRANT
SIOUX
EMMONS
LOGAN
LA MOURE
RANSOM
RICHLAND
SARGENT
DICKEY
MC INTOSH

Figure 28. Core slab of bioturbated, green clayshale from the Icebox Formation. NDGS Well No. 7020, Grant County, 10,287 feet.

Figure 29. Orthid brachiopods in green clayshale from the Icebox Formation. NDGS Well No. 7146, Burleigh County, 5,268 feet.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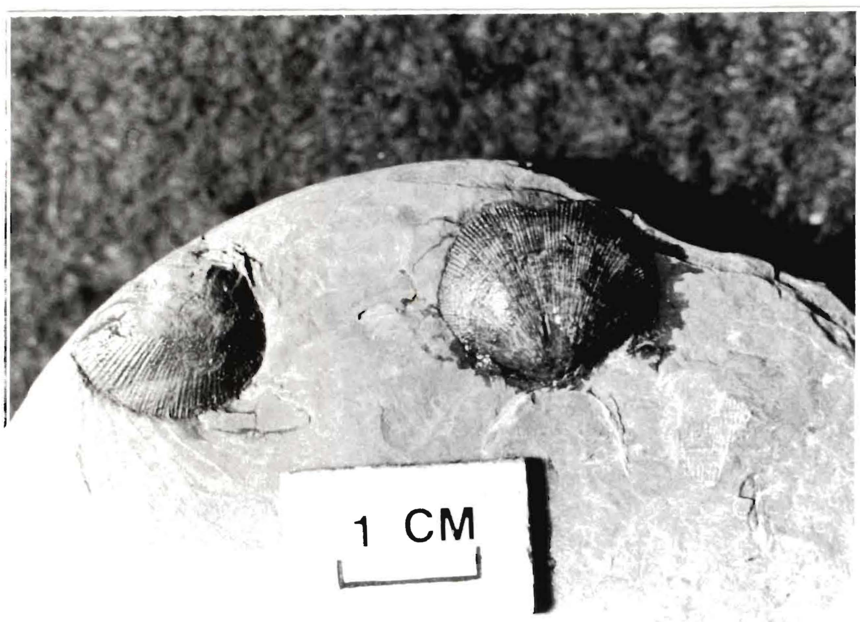
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Dakota (Fig. 27). The first two of these lithosomes, at least, are characterized by fine- to medium-grained, rounded to well-rounded, light to medium gray quartz wacke. The sandstone body in Divide County is highly bioturbated and argillaceous and, in places, contains cross-laminations. The contact between the Divide County sandstone lithosome of the Icebox and the overlying green clayshale is gradational, with the upper 10 feet (3 m) of this sandstone becoming increasingly argillaceous before grading into siltstone, and finally into shale. The sandstone in Divide County attains a maximum thickness of about 45 feet (14 m). The quartz wacke of the Grand Forks County lithosome is also gradational with the enclosing greenish gray clayshale of the Icebox Formation. The sandstone lithosome of Grand Forks County has an elongate shape and is up to 60 feet (18 m) thick. The sandstone lithosome in southwestern North Dakota (as yet uncored) underlies large portions of Grant, Morton, Adams, Hettinger, and Stark Counties. This lithosome is up to 30 feet (9 m) thick and well log responses indicate that the sandstone is interbedded with thin layers of shale.

Roughlock Formation

The Roughlock Formation is transitional between the noncalcareous clayshale of the underlying Icebox Formation and the limestone of the overlying Red River Formation and contains characteristics of both. Well log responses indicate that the Roughlock is relatively homogeneous in lithology throughout the state and core descriptions indicate that it is composed mostly of a nodular, argillaceous limestone. A notable exception to this homogeneity is the presence of a sandstone lithosome, up to 40 feet (12 m) thick, in south-central North Dakota (Fig. 30).

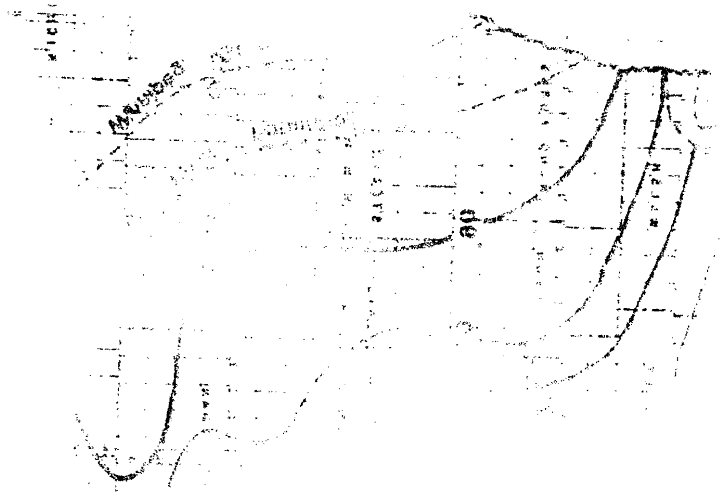
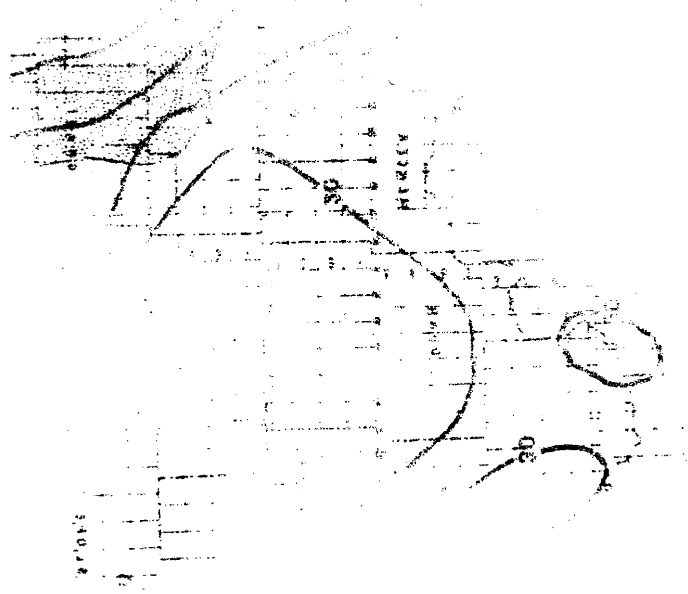
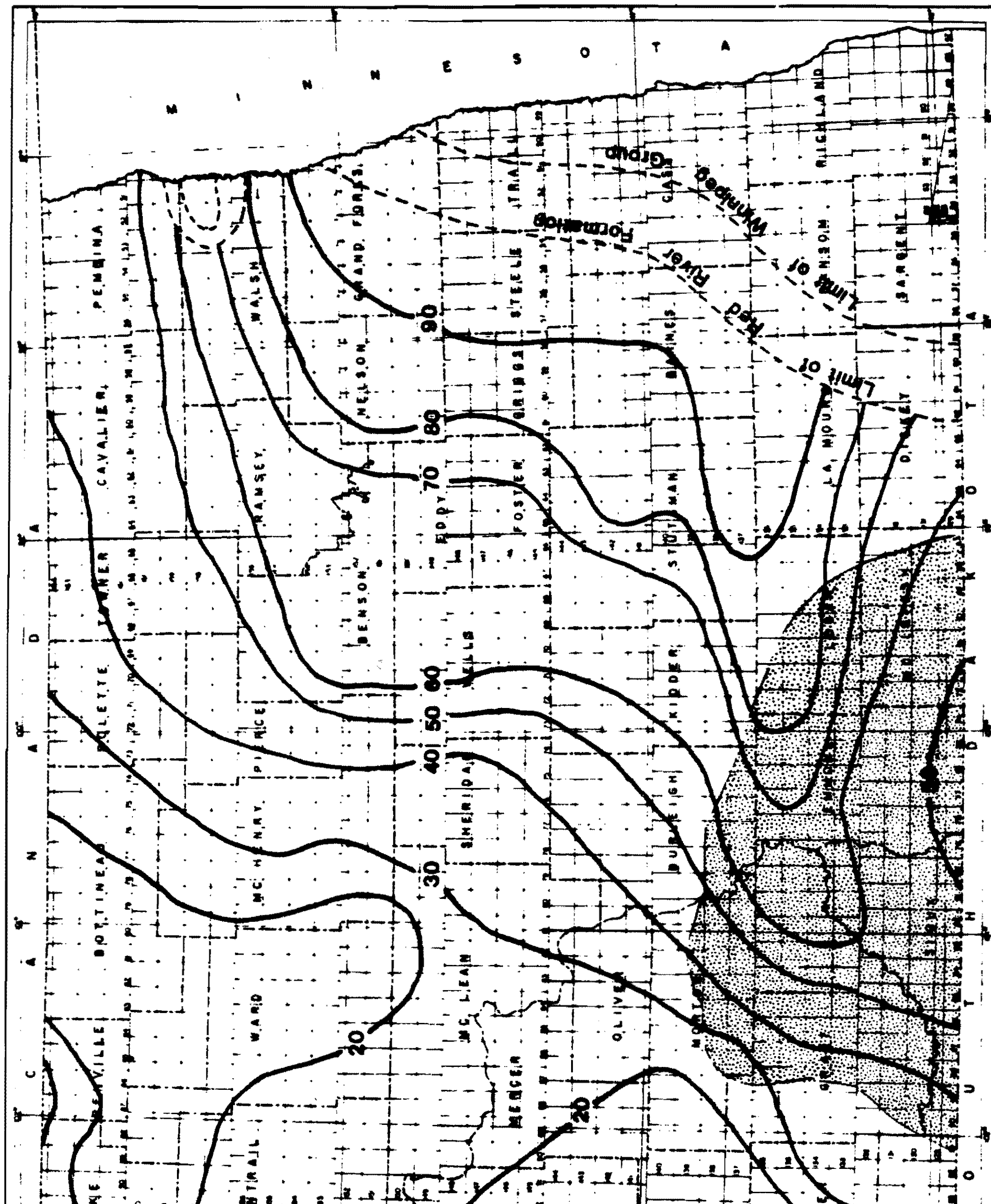


Figure 30. Isopach map of the Roughlock Formation in North Dakota. The contour interval is 10 feet (3 m). The Roughlock section between the dashed lines in eastern North Dakota may be incomplete due to post-Ordovician erosion.




M I N N E S O T A
C A N A D A
S O U T H D A K O T A
Limit of Red River Formation
Limit of Winnipeg Group
Sandstone lithosome
NORTH DAKOTA
PEMBINA
CAVALIER
TOWNER
ROLETTE
BOTTINEAU
RENVILLE
BURKE
DIVIDE
WALSH
RAMSEY
BENSON
PIERCE
MC HENRY
WARD
MOUNTRAIL
WILLIAMS
GRAND FORKS
NELSON
EDDY
WELLS
SHERIDAN
MC LEAN
MERCER
DUNN
MC KENZIE
BILLINGS
GOLDEN VALLEY
STEELE
TRAILL
CASS
GRIGGS
FOSTER
BARNES
STUTSMAN
KIDDER
BURLEIGH
OLIVER
STARK
HETTINGER
SLOPE
ADAMS
BOWMAN
RICHLAND
RANSOM
SARGENT
LA MOURE
DICKEY
10
0
20
30
40
50
60
70
80
90

Although the interval of this lithosome has not yet been cored, well log responses (Fig. 31) indicate that it is composed of sandstone interbedded with thin shale beds.

The isopach of the Roughlock Formation (Fig. 30) shows that it is 90 feet (27 m) thick just west of the area where it is erosionally truncated, near the eastern border of the state. The Roughlock gradually thins to the west and averages about 20-30 feet (6-9 m) thick in the western third of the state; it thins to a feather edge near the northwest corner of the state.

The dominant lithology of the Roughlock Formation is a limestone which is characterized by a nodular, light gray, microsparite in a matrix of medium dark gray, argillaceous, dolomitic biomicrite. As shown in Figure 32 the light gray, microsparite appears nodular or in patterns reminiscent of boudinage. The nodules have a microspar fabric with interstitial silt and clay, contains fine dolomite rhombs, and are moderately fossiliferous. The matrix of the nodular limestone lithotype, the dark gray biomicrite, contains more silt, clay, and dolomite rhombs than the enclosed light gray, nodular microsparite. The dark gray matrix also contains more fossils than the nodules (Fig. 33). Fossils within this lithotype include fragments of brachiopods, trilobites, echinoderms, and unidentified fossils.

The Muav Limestone (Middle Cambrian), which occurs through the Grand Canyon, Arizona, has been described as a marbled or mottled limestone (McKee, 1945) and as a nodular, clayey limestone (Wanless, 1979, p. 441). Wanless pointed out that the terms "mottled" or "marbled" imply burrowing and, because the nodules do not appear to be the result of organism activity, these terms are inappropriate as

Figure 31. Typical log response of the Winnipeg Group in southwestern North Dakota, showing the sandstone layer within the Roughlock Formation.

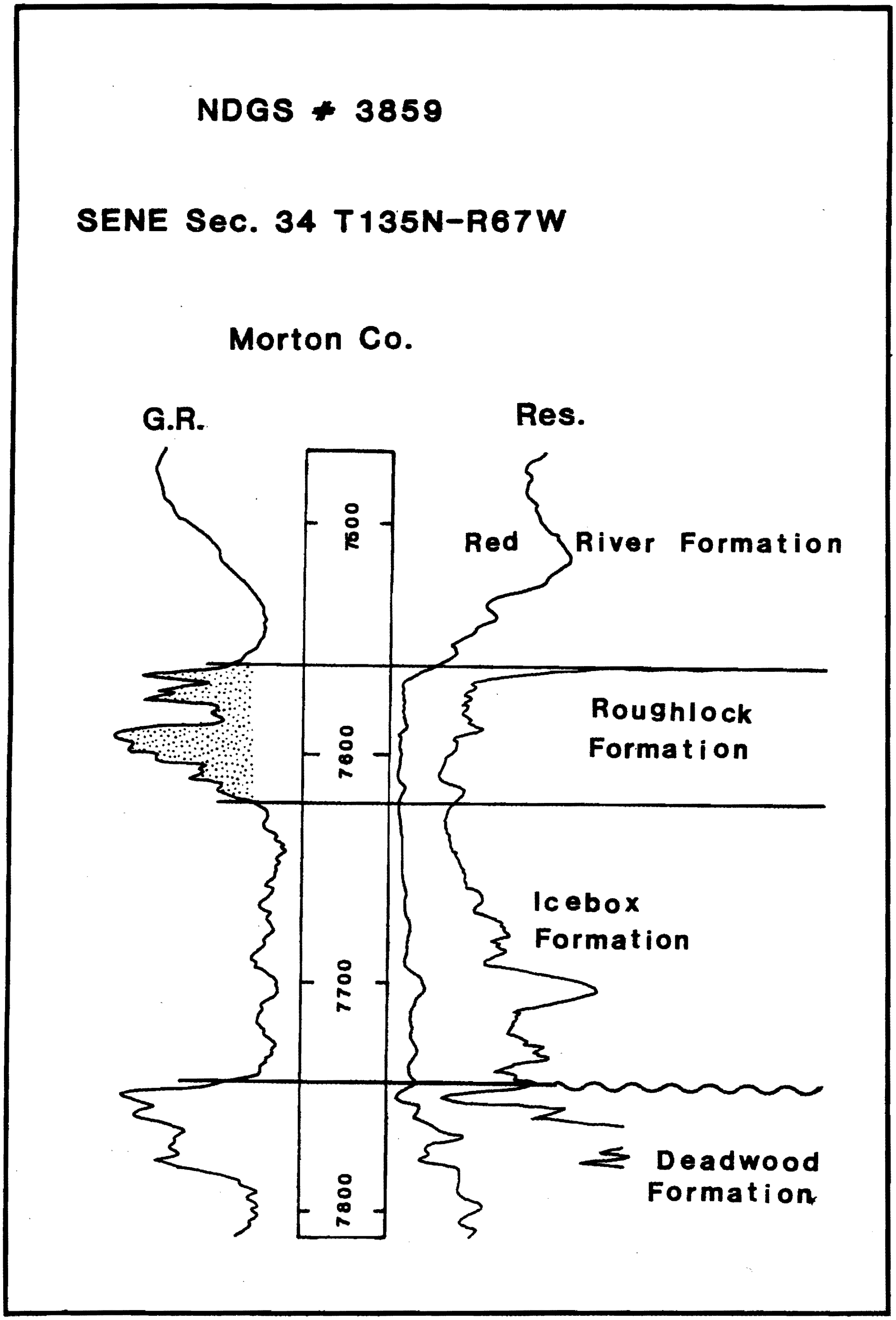
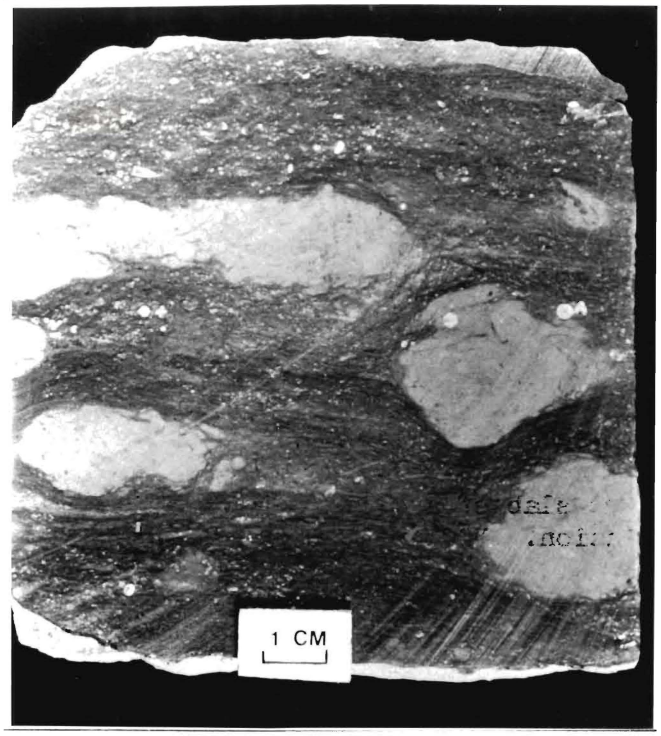

NDGS # 3859
SENE Sec. 34 T135N-R67W
Morton Co.
G.R.
Res.
7500
7600
7700
7800
Red River Formation
Roughlock Formation
Icebox Formation
Deadwood Formation

Figure 32. Core slab of argillaceous, nodular limestone from the Roughlock Formation. NDGS Well No. 20, Ramsey County, 3,069 feet.

Figure 33. Photomicrograph of argillaceous, nodular limestone (Fig. 32) from the Roughlock Formation. (Fossil fragment - f). NDGS Well No. 20, Ramsey County, 3,069 feet. Bar equals 0.5 mm.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f
f
f

descriptors of the Muav. Wanless (1979, p. 441) described nodular limestones such as the Muav as being the result of non-sutured seam solution. According to Wanless (1979, p. 439), a limestone with a high percentage of clay and silt, such as the Muav, responds to pressure by dissolution throughout, rather than along selected surfaces (such as might form stylolites). Non-sutured seam solution tends to form anastamosing swarms of thin clay seams, also known as microstylolites or microstylolite swarms (Wanless, 1979). He explained (p. 441) that microstylolites form where silt or clay within a microstylolite restrict the seam as a pathway for fluid migration and act as a glide surface, where slippage relieves stress. The Roughlock is remarkably similar in description and appearance to the Muav Formation. It is suggested here that the argillaceous, nodular limestone of the Roughlock in North Dakota formed as the result of non-sutured seam solution.

Near the contact with the underlying Icebox Formation, the Roughlock consists of interbedded argillaceous limestone and calcareous shale; in most locations the contact appears to be gradational. The contact with the overlying Red River Formation also appears to be gradational. The limestone of the Roughlock becomes gradually less argillaceous upward into the Red River.

Sandstone Diagenetic Features

Diagenesis, as used here, includes all the post-depositional processes, both chemical and physical, which affect sediment, up to the lowest grade of metamorphism (Pettijohn and others, 1973, p. 386). Particularly in the deepest part of the basin, conditions for diagenetic alteration of Winnipeg rocks has been optimum. The great depth of burial of Winnipeg strata -- up to 15,000 feet (4600 m) -- increases the temperature and the pressure, both of which have tended to increase the diagenetic effects. Diagenesis in the Winnipeg is related to the type of lithology and therefore to the environments of deposition. Another factor which seems to have affected diagenesis is the lithology of the surrounding sedimentary rock. The diagenetic history of rocks of the Winnipeg Group appears to have been quite complex. Several diagenetic features are commonly present in one sample; this suggests that more than one episode of diagenesis has affected Winnipeg Group rocks.

Diagenesis of the rocks of the lower member of the Black Island Formation was dominated by the formation of hematite cement, which gives the red-bed lithofacies its dark reddish brown color. In the sandstone, the iron oxide is present as pore filling (Fig. 15). The red color of the clayshale and mudstone of this lithofacies indicates that iron oxide ions have been adsorbed on clay-mineral surfaces (Blatt and others, 1980, P. 350). There are two hypotheses concerning the origin of the red color (and the origin of red-beds). Krynine (1949) suggested that red-beds were formed by the erosion and redeposition of red lateritic soils from moist, tropical climates. Another hypothesis contends that the hematite, which gives red-beds their color, forms in place. Although both hypotheses probably contain some truth, Walker (1967) was able to demonstrate that red-beds formed in place in hot, arid, and semiarid climates due to intrastratal alteration of iron-bearing detrital grains. In other words, red-beds need not be the result of transport of grains from a hot, humid climate, and diagenetic processes are probably the most important factor in the formation of red-beds.

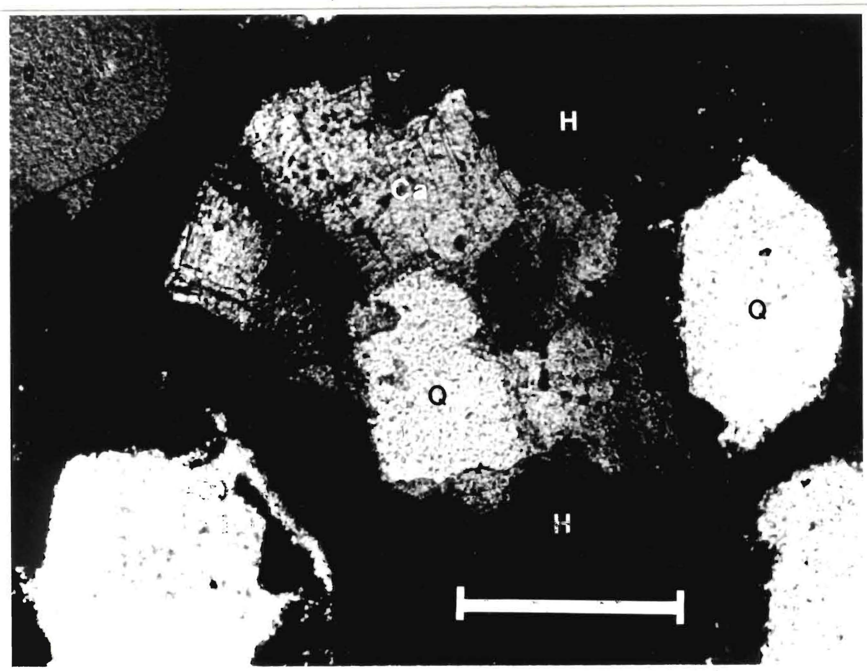
Another diagenetic feature in the lower Black Island reddish brown, quartz arenite is the syntaxial quartz overgrowth. Cross-cutting relationships indicate that the quartz overgrowths were the first cement to form; as shown in Figure 15, quartz overgrowths have been replaced by hematite cement. There are at least two hypotheses for the origin of the dissolved quartz necessary for the formation of quartz overgrowths. Weyl (1959) suggested that silica is released due to pressure solution between quartz grains and later reprecipitated as overgrowths on quartz grains. Sibley and Blatt (1976) determined intergranular pressure solution to be only a minor source of silica for quartz overgrowths. They suggested that silica-saturated, surface-derived, ground water is a more likely source for the silica. Few of the quartz grains in the lower member of the Black Island have sutured contacts. This suggests that little pressure solution occurred and that much of the silica was derived from ground water.

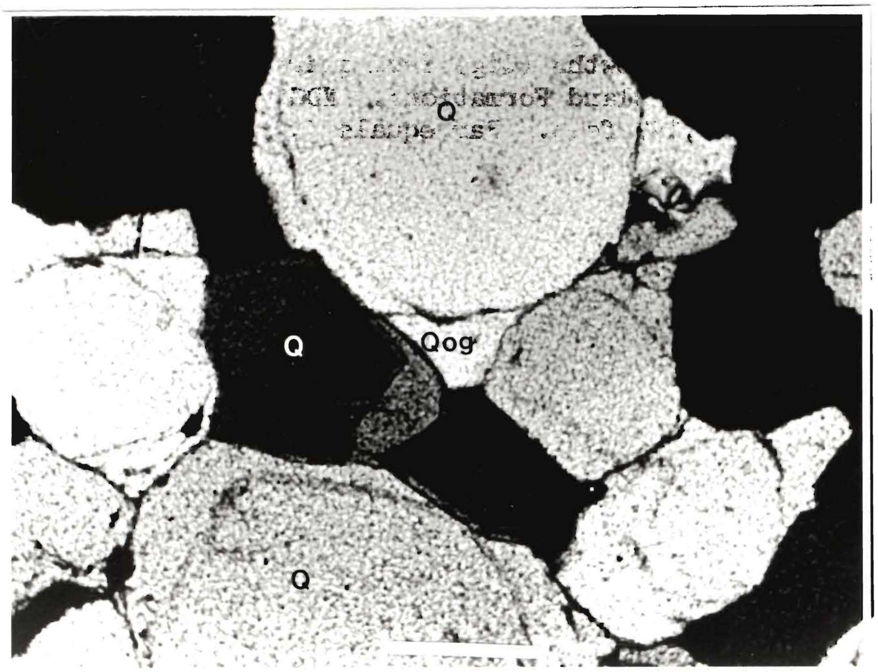
Carbonate cement appears to have been introduced after the cementation of the grains by the quartz and hematite. There may have been more than one episode of carbonate crystallization. First, calcite crystallized in the pore spaces not filled by the quartz or hematite. Thereafter, calcite has, in places, replaced some of the original detrital quartz grains. As shown in Figure 34, a quartz grain is partially replaced by calcite, yet retains the original rounded morphology of the initial quartz grain.

The last diagenetic event in the sandstone of the lower member of the Black Island Formation was the replacement of some of the calcite by anhydrite. Anhydrite is relatively uncommon in the sandstone of the lower member of the Black Island.

Figure 34. Photomicrograph showing calcite (Ca) replacing a detrital quartz grain (Q) from the red-bed lithofacies (hematite cement - H). (lower member, Black Island Formation). NDGS Well No. 3268, Billings County, 12,627 feet. Bar equals 0.25 mm.

Figure 35. Photomicrograph showing detrital quartz grains (Q) rimmed by quartz overgrowths (Qog) from quartz arenite lithotype (upper member, Black Island Formation). NDGS Well No. 1385, Williams County, 14,147 feet. Bar equals 0.5 mm.


H
Ca
Q
Q
H


Q
Q
Qog
Q

The cumulative effect of these processes has been to reduce greatly the original porosity in the lower member of the Black Island. Hematite cement, quartz overgrowths, and calcite cement appear to have removed most of the primary porosity although dissolution of calcite has produced minor secondary porosity.

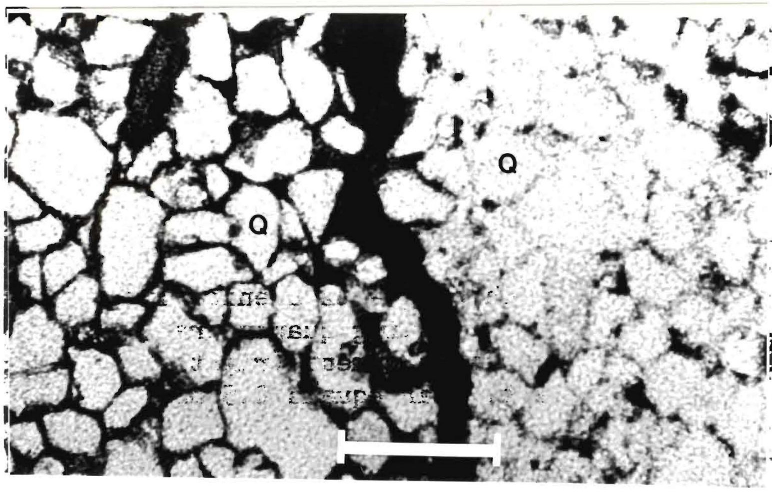
Diagenesis of the upper member of the Black Island Formation appears to have been largely controlled by the original composition of the strata. Strata which originally contained a high percentage of interstitial clay tend to have a greatly reduced number of quartz overgrowths. Figure 35 shows a quartz arenite with a high degree of quartz cementation and very little interstitial clay. Heald and Larese (1974, p. 1271) reported that coatings of chlorite, illite, hematite, chert, or carbonate on quartz grains may inhibit quartz cementation. Where present, interstitial clay was probably introduced into the Black Island sediment at the time of deposition, either as detrital grains or as the result of heavy bioturbation. Figure 36 shows the contrast between rock with interstitial clay (on the left) and with little clay (on the right). The side with a small amount of interstitial clay (right) is cemented primarily by quartz overgrowths. In contrast, the side with interstitial clay (left) shows almost no quartz cement. Figure 36 and other samples support Heald and Larese's (1974) contention that clay coatings on quartz grains tend to inhibit the formation of quartz overgrowths.

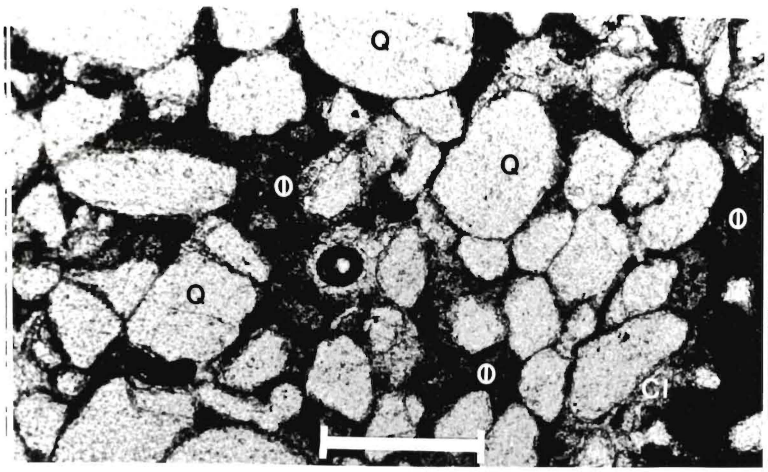
Porosity within the upper member of the Black Island is highly variable. Very low porosities are found in sandstones with either extensive quartz overgrowths or a large amount of clay matrix. Elsewhere, porosity can be quite high. Higher porosities are generally

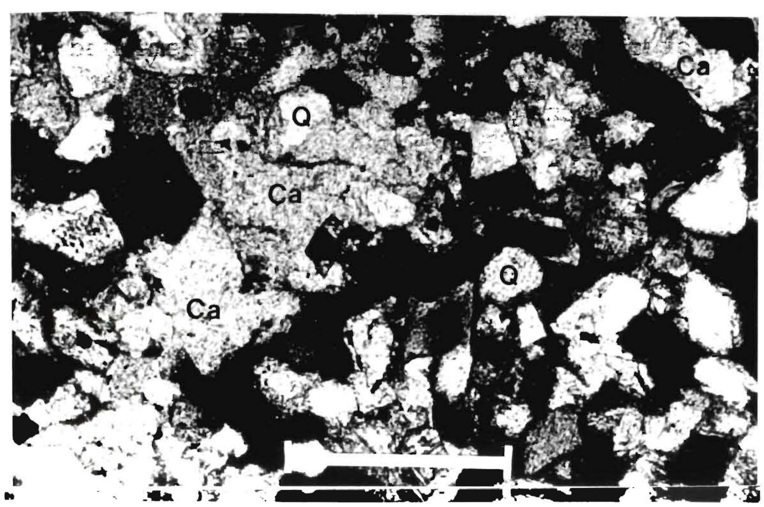
Figure 36. Photomicrograph of quartz arenite lithotype (upper member, Black Island Formation) showing quartz grains (Q) with interstitial clay (left) and quartz cement (right). NDGS Well No. 6148, Dunn County, 13,441 feet. Bar equals 0.5 mm.

Figure 37. Photomicrograph showing high porosity in quartz wacke from the quartz arenite lithotype (upper member, Black Island). (Quartz grain - Q, porosity - 0). NDGS Well No. 8169, Stark County, 11,362 feet. Bar equals 0.25 mm.

Figure 38. Photomicrograph showing calcite cemented (Ca) quartz arenite from quartz arenite lithotype (upper member, Black Island Formation). (Quartz grain - Q). NDGS Well No. 7571, Burleigh County, 5,307 feet. Bar equals 0.25 mm.


Q
Q


Q
Φ
Q
Φ
Q
Φ
Cl

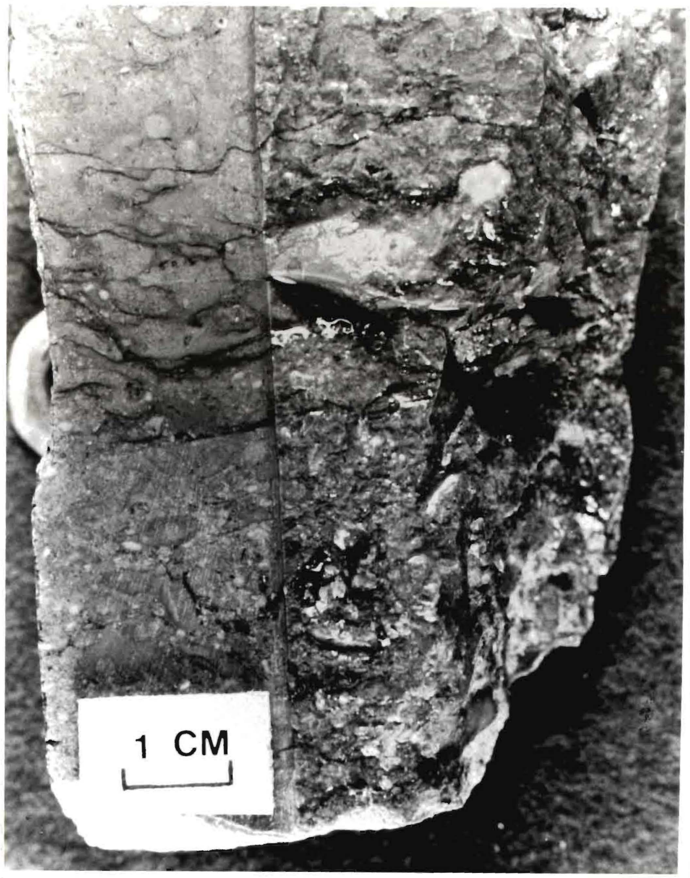

Ca
Q
Ca
Q
Ca

associated with those sandstones with minor amounts of clay rimming the detrital quartz grains. Figure 37 shows a photomicrograph of a quartz wacke with high porosity. The clay rimming the grains may have inhibited the formation of quartz overgrowths.

The diagenetic features at the base of the upper member of the Black Island are in places influenced by the lithology of the underlying unit. Where the underlying strata are dolomitic limestones of the Deadwood Formation, as in Figure 38, the lowermost Black Island is composed of sandstone with a carbonate cement.

Figure 39. Core slab of the uppermost Deadwood Formation in McKenzie County - - quartz arenite. NDGS Well No. 2373, 14,267 feet.

Figure 40. Core slab of the uppermost Deadwood Formation in southern Billings County, North Dakota - - limestone. NDGS Well No. 3268, 12,631 feet.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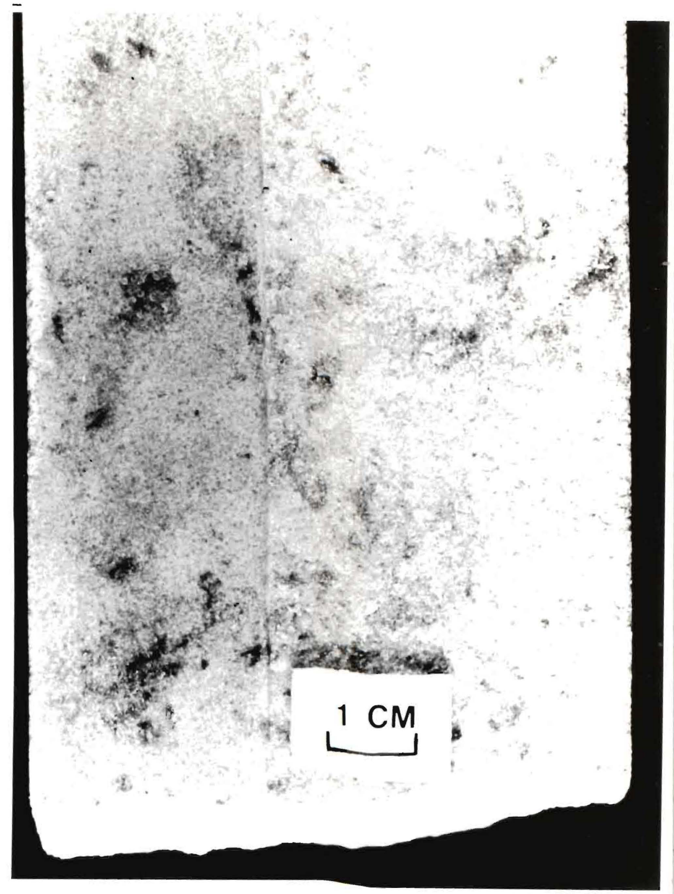
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INTERPRETATIONS

Environmental Interpretation

Introduction

Environments of deposition were interpreted for four units of the Winnipeg Group: the lower and upper members of the Black Island Formation, the Icebox Formation and the Roughlock Formation. Environmental interpretations of these units were made by comparing lithologic and stratigraphic information to process-related analogues in modern and ancient rocks. It is possible, however, that no modern environments accurately represent those environments under which the Winnipeg was deposited. Vascular plants did not invade the land until Late Silurian time (Levin, 1978, p. 347); thus, the surface upon which the Middle Ordovician transgression occurred was plantless and probably had been exposed for millions of years (Witzke, 1980). Lack of vegetation prevented the formation of a soil horizon and the surface may have been composed of a regolith. Sedimentation rates and patterns in an environment such as this must have been significantly different than any modern environment. Also, it is questionable whether there are any modern analogues to the epeiric seas such as were present during the Paleozoic. Shaw (1964) suggested that tides in the Paleozoic epeiric seas were either of a very small range or nonexistent. However, Schopf (1980, p. 83) suggested that tides probably did exist in epeiric seas during the Paleozoic and may have been greater than they are today. In light of the possible differences between ancient and modern environments, caution must be exercised in describing ancient environments in terms of modern depositional models.

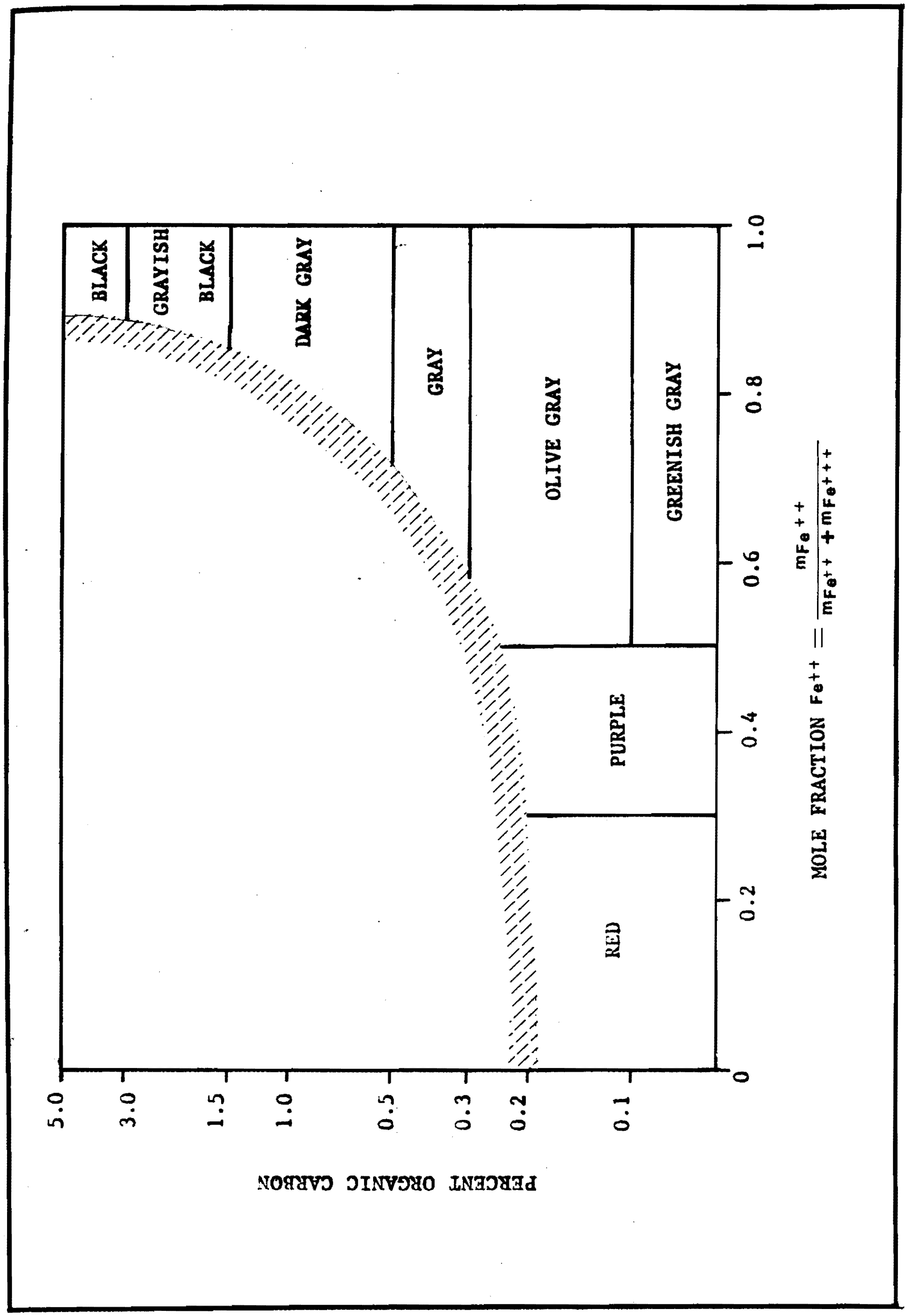
The terms nearshore and offshore, as suggested by Clifton and others (1971), were used in this study to describe environments in which some of the units of the Winnipeg Group were deposited. As used by Clifton and others (1971, p. 652), the nearshore refers to the zone seaward from the shoreline to somewhat beyond the breaker zone -- the zone of wave-induced nearshore currents. Clifton and others (1971, p. 652) used the term offshore for the area seaward of the nearshore zone. Although Clifton and others (1971) originally used these terms to describe marginal marine environments near the coast of Oregon, it is felt that the terms nearshore and offshore have fewer tectonic implications than terms such as tidal or shelf and may therefore be appropriate for use in an epeiric sea such as that in which the Winnipeg was deposited.

Lower Member of the Black Island Formation

The reddish brown color is the most obvious characteristic of the lower member of the Black Island Formation; both the quartz arenite and clayshale, the dominant lithotypes of the red-bed lithofacies, are predominantly a dark reddish brown color. Red sediments are usually indicators of continental environments, although other environments can also produce this color. For example, Reineck and Singh (1980, p. 488) stated that most of the ocean's basins show large areas covered with red to reddish brown colored clay. Nevertheless, Heckel (1972, p. 229) noted that detrital red-beds of all grain sizes are mainly nonmarine in origin. Walker (1967) and Berner (1971, p. (198) concluded that continental red sediments are usually produced by oxidizing depositional conditions rather than as detritus from red soils. Tomlinson (1916) and McBride (1974) suggested that, although iron is necessary for the formation of red-beds, the total amount of iron is less important than the ferric/ferrous ratio. In shales, high ferric/ferrous ratios are associated with red colors and low ratios with greens. Potter and others (1980, p. 55) suggested that the amount of organic carbon is another important control of color in sediments. Figure 41 shows the relationship of shale color to carbon content and the oxidation state of iron. Potter and others (1980, p. 56) suggested that color in shales is ultimately controlled by the amount of organic matter present, because the ferric/ferrous ratio is controlled by the oxidation rate, which is in turn controlled by the amount of organic matter in the sediment. Since most of the shale of the red-bed lithofacies is reddish brown in color, Figure 41 suggests that this lithotype contains a low percentage of organic carbon and a high ferric/ferrous ratio. A low percentage of organic carbon tends to support a non-marine origin for the reddish brown clayshale lithotype. There were no land plants at the time of deposition to provide organic material to the sediments and thus cause the shale to be darker.

Turner (1980, p. 66) recognized three major associations where red-beds occur: alluvial, desert, and deltaic plain associations. He reported (p. 126) that deltaic plain red-beds are usually deposited in moist, tropical climates. North Dakota appears to have been located in the low latitudes during Middle Ordovician time (McElhinny and Opdyke, 1973; Dott and Batten, 1981). Turner (1980, p. 67) listed several criteria which tend to characterize deltaic plain depositional environments, including sandstone channel and bank deposits of a red or drab color, pedogenic modification of floodplain deposits, mudstone floodplain deposits of red or variegated colors, and fining- and

Figure 41. Relationship of shale color to carbon content and oxidation state of iron (from Potter and others, 1980, p. 55).


BLACK
GRAYISH BLACK
DARK GRAY
GRAY
OLIVE GRAY
GREENISH GRAY
PURPLE
RED
PERCENT ORGANIC CARBON
5.0
3.0
1.5
1.0
0.5
0.3
0.2
0.1
0
0.2
0.4
0.6
0.8
1.0
MOLE FRACTION $Fe^{++} = \frac{mFe^{++}}{mFe^{++} + mFe^{+++}}$

coarsening-upward sequences. Walker (1967, p. 355) described modern red-beds forming in the Sonoran desert, Baja California, and reported that facies relationships at this locale reflected deposition in fluvial and fluvial-marine transitional environments. The red-bed lithofacies of the lower member of the Black Island exhibits many of the above characteristics. The structureless nature of the clayshale (Fig. 16), which composes much of the red-bed lithofacies, suggests rapid deposition from suspension. Parallel, horizontal stratification, such as the horizontally laminated siltstone shown in Figure 20, represents episodic sedimentation in still water. Mudstones interbedded with sandstones (Fig. 18) indicate intermittent slack water periods when clay settled out between periods of traction transport of sand and silt. Cross-stratification, such as that of the fine-grained sandstone of Figure 17, records relatively high energy, turbulent flow conditions. The occurrence of thin, cross-stratified sandstone layers within the shale unit suggests widely fluctuating current conditions, which might be expected within a deltaic plain environment. Mudcracks, as shown in Figure 19, are usually caused by desiccation of clay under subaerial conditions. Potter and others (1980, p. 33) reported the formation of mudcracks under subaqueous conditions, but the red color and the described features of associated rocks rules out a subaqueous origin for these mudcracks. The thick deposits of reddish brown quartz arenite of the red-bed lithofacies may represent bank deposits of distributary channels. The above features, plus the sometimes red and green color of the clayshales, tend to support a deltaic plain origin for the rocks of the red-bed lithofacies of the lower member of the Black Island. A major criterion for the interpretation of this unit is the reddish-brown color, even though color, by itself, is not always an accurate indicator of environments. However, the color, together with the associated sedimentary structures and the rock associations detailed above, points to a deltaic plain origin for the rocks of the red-bed lithofacies of the lower member of the Black Island.

The environment in which the green quartz wacke lithofacies of the lower member of the Black Island Formation was deposited has not been positively identified. However, the difference in lithology and the sharp contacts suggest that it has a different origin than that of the red-bed lithofacies. There are at least two possibilities for the origin of the green quartz wacke lithofacies. These rocks may have formed as the result of the weathering of preexisting strata of the lower member of the Black Island Formation. A different and more likely explanation for the origin of this lithofacies is that these rocks were the initial deposits of the transgression that later deposited the quartz arenite of the upper member of the Black Island. Rock associations tend to support the second of these hypotheses. The occurrence of the green quartz wacke lithofacies in both the lower and upper members of the Black Island may be evidence of intertonguing between the two members. The presence of intertonguing is important because its presence would suggest that a facies relationship exists between at least part of the lower and upper members of the Black Island.

Upper Member of the Black Island Formation

The upper member of the Black Island Formation is interpreted in this study to have been deposited in a nearshore environment. Nearshore environments exist in the shallow waters that lie between those parts of the sea dominated by beach processes and those dominated by deep oceanic processes, with depths ranging from about 30-650 feet (10-200 m) and are often storm-dominated (wind and wave driven). Johnson (1978, p. 207) noted that, although modern shelf environments may be atypical as compared to ancient epeiric seas, they still provide a good basis for reconstruction of the physical and biological processes operating in ancient shallow seas. Sedimentation in the early Williston Basin, however, probably had some significant differences from a modern environment. The rate of supply of the sediment to the Middle Ordovician Williston Basin may have been different than depositional systems which empty into most modern continental shelf environments. The exposed, weathered surface of the Deadwood Formation was probably the primary source for the Black Island Formation. The well-rounded, well-sorted nature of most of the sandstone of the Black Island supports this premise. In contrast, most modern environments contain a vegetative cover which probably tends to reduce the rate of denudation. Another factor which must be considered when comparing ancient epeiric seas to modern continental shelf-margin environments is the relief of the surrounding area. There is no evidence that there were any major structural highs in the area of the Williston Basin during the Middle Ordovician. Another difference between the ancient epeiric sea margins and modern shelf environments is the type and intensity of the shelf hydraulic regime. It is probable that a continental-margin, shelf environment would experience higher energy conditions than an interior epeiric sea, considering the greater fetch of the waves and possible greater tidal influence. If the aforementioned differences in ancient epeiric seas and modern shelf seas did indeed exist, more bed forms and more sand transport might be expected in a continental-margin nearshore environment than that of the sea of the Middle Ordovician Williston Basin.

The environment under which the upper member of the Black Island Formation was deposited may have been somewhat similar to that of the modern environment on the Oregon coast, where a sand facies controlled by sediment supply, shelf hydraulic regime, and burrowing benthic organisms exists (Clifton and others, 1971). The high relief of nearby uplands on the Oregon coast is an obvious difference between that environment and that of the Williston Basin during the Middle Ordovician. It is unclear which of the two above named environments would receive a greater rate of sedimentation; the Williston Basin of the Middle Ordovivian probably had a greater supply of friable, readily accessible clastics but also probably had less relief in the surrounding lands which drained into it than that of the present day Oregon coast. Clifton and others (1971) noted that, in general, on the Oregon coast, sand occurs in the nearshore environment into water depths of 160-320 feet (50-100 m). Also, primary sedimentary stuctures are largely obliterated due to extensive bioturbation, but stratification is occasionally preserved. Where present, the stratification is primarily horizontal lamination which Kulm and others (1975), also working on the Oregon coast, considered to be the result of upper flow regime conditions. Johnson (1978, p. 223) suggested that horizontal laminations may be due to deposition from suspension or wave reworking of unidirectional cross laminations.

The upper member of the Black Island Formation is dominated by the rocks of the the quartz arenite lithofacies. The parallel laminations of the quartz arenite lithotype may represent upper flow regime conditions with deposition from suspension. Hummocky cross-stratification may also be present in the upper member of the Black Island Formation. Hummocky cross-stratification is characterized by gently undulating bed boundaries with laminae almost parallel to the lower bounding surface (Reineck and Singh, 1980, p. 100) and has been shown to occur in the lower part of shore-line sequences, especially under high wave conditions. The large scale, together with the roughly horizontal orientation of the laminae, makes hummocky cross-stratification difficult to recognize in cores; hummocky cross-stratification may be present in the Black Island where stratification boundaries are represented by minor breaks in the quartz arenite lithotype. The paucity of fossils within the quartz arenite lithofacies supports an interpretation of a nearshore environment in that the high energy of nearshore conditions increases the mobility of the substrate, making conditions less favorable for the survival of benthos.

A nearshore interpretation for the quartz arenite lithofacies of the upper member of the Black Island is also supported by the nature of the adjacent rock units. The upper member is conformably underlain by what are interpreted to be the the continental deltaic plain deposits of the lower member of the Black Island and conformably overlain by a clayshale of the Icebox Formation (which is interpreted here to be of offshore origin). The position of the upper member of the Black Island between continental deposits and a thick shale section makes an nearshore environment interpretation for that unit reasonable.

The rocks of the green quartz wacke lithofacies of both the lower and upper members of the Black Island are lithologically very similar. It is not likely that weathering of rocks as different as those of the red-bed lithofacies and the quartz arenite lithofacies would result in the same lithology. It is more plausible that the green quartz wacke lithotype of the two members is similar as a result of similar depositional conditions. The occurrence of the green quartz wacke lithofacies interbedded with lithofacies of both the lower and upper members suggests that the green quartz wacke may be transitional between the other lithofacies in the lower and upper members and may represent the initial deposits of the Middle Ordovician transgression. If these deposits are indeed of the same origin, the intertonguing supports the interpretation that a facies relationship exists between the lower and upper members of the Black Island.

Icebox Formation

The Icebox Formation is interpreted to have been deposited in an offshore environment, adjacent to and seaward from a nearshore environment. Marine invertebrates, such as the orthid (Fig. 30) and strophomenid brachiopods identify the Icebox as marine in origin. Johnson (1978, p. 229) suggested that the presence of brachiopods indicates an open marine environment with normal salinity ranges.

The environment in which the Icebox was deposited may be similar to that of the "mud facies" off the coast of Oregon, described by Kulm and others (1975, p. 154), where the mud facies is located in an offshore environment, seaward from the sand facies of the nearshore. A similar configuration probably existed during the Middle Ordovician when clay or mud of the Icebox was deposited seaward of the nearshore sand deposits of the upper member of the Black Island.

The clayshale lithotype of the Icebox Formation may also be similar to the muddy shelf sediments of the Jurassic European epeiric sea. Of the three lithofacies recognized in that sea (Johnson, 1978, p.256) (normal shale, restricted shale, and bituminous shale), the clayshale of the Icebox most closely resembles Johnson's normal shale lithofacies, which is characterized by burrowing and infaunal organisms. The presence of epifaunal suspension feeders (brachiopods) and abundant horizontal burrows (Fig. 29) suggests that the upper portion of the substrate contained mild oxidizing conditions.

The three sandstone lithosomes of the Icebox Formation probably represent three different environments of deposition in the three different localities in which they exist (Fig. 28). The sandstone lithosome in northwestern North Dakota (Divide County) probably represents a nearshore deposit similar to that of the quartz arenite lithofacies of the upper member of the Black Island. The lower part of this lithosome has not been cored but the cross-laminated sandstone present in the middle of this lithosome, suggesting deposition under lower flow regime conditions, is overlain by horizontally laminated and bioturbated sandstones which become increasingly shaly upward until they grade into a typical Icebox clayshale section. Log responses indicate that the lower contact of the Divide County lithosome is also gradational from the underlying clayshale. This sandstone lithosome may well be a tongue of the upper member of the Black Island; more data may show the upper member of the Black Island and the sandstone lithosome of the Icebox in Divide County to be physically continuous. The depositional sequence in the Icebox in Divide County suggests that a transgression (marked by the transition from sandstone of the Black Island to the clayshale of the Icebox) was followed by a regression where nearshore deposits (sandstone lithosome of the Icebox Formation) retreated as far basinward as northeastern North Dakota. The retreat of the sea was followed by another transgression, as signified by the clayshale of the Icebox overlying the sandstone of the Icebox lithosome. The intertonguing of sandstone and clayshale suggests that a facies relationship exists, at least in part, between the upper member of the Black Island Formation and the Icebox Formation.

The Icebox sandstone lithosome located in Grand Forks County (Fig. 27) may be an offshore bar deposit. Andrichuk (1959, p. 2354) reported the "Carman sandstone", a long, narrow sandstone body, to exist within the shale of the Winnipeg (his "upper unit") in southern Manitoba. Vigrass (1971, p. 232) interpreted the "Carman Sandstone" to be an offshore deposit which was deposited up to 100 miles (160 km) from the shore. Like the "Carman sandstone body", the sandstone lithosome within the Icebox Formation in Grand Forks County is composed of a well-sorted, commonly argillaceous, and friable sandstone. Both sandstone bodies are elongate in shape. The Grand Forks sandstone is oriented with its elongate axis east-west, which is the same orientation as the "Carman sandstone" body. The similarities between the Carman and Grand Forks County sandstone bodies of the Icebox Formation suggest that they may have been deposited under similar conditions.

A third Icebox sandstone lithosome, located in southwestern North Dakota, is as yet uncored; the log response indicates that the unit consists of interbedded sandstone and shale. The orientation of the lithosome and the interbedding of sandstone and shale suggest that this body may be a deltaic deposit with a source to the south.

Roughlock Formation

The Roughlock Formation is also interpreted to have been deposited in an offshore environment. Most of the Roughlock in North Dakota is composed of an argillaceous, nodular limestone. The rich and diverse faunal assemblage within this formation, which includes brachiopods, echinoderms and trilobite fragments, suggests deposition in an open-marine environment with normal salinities.

Wilson (1975) discussed the conditions necessary for the production of carbonates, including: warm water, light, and an absence of siliciclastics. Implied within these conditions is a close proximity to the equator and a relatively shallow depth. Wilson (1975, p. 26) listed the characteristics of an undathem, carbonate-shelf, lithofacies. The environment in which such a lithofacies forms exists in water with depths from 30 to hundreds of feet (10 to hundreds of metres), is generally oxygenated, and has normal marine salinity; the depth is below that of normal wave base but may be affected by occasional storms. Such a lithofacies contains fossiliferous limestone, is thoroughly burrowed, contains wavy to nodular beds, and may contain siltstone and shale. The Roughlock Formation, which is a shaly, nodular, fossiliferous limestone, fits the description of strata deposited in an unda, carbonate-shelf, environment.

The environmental conditions in which the Roughlock was deposited appear to be similar to those of the Icebox Formation (nearshore) except for a decrease in the amount of detrital input. A decrease in the influx of terrigenous material fulfilled a requirement for the production of the carbonates of the Roughlock.

The lobate shape of the areal extent of the Roughlock sandstone lithosome (Fig. 30) and its interbedded sandstone and shale nature (Fig. 31) suggest that it may have a deltaic origin. The Roughlock sandstone lithosome is similar in lithology and in morphology to the sandstone lithosome of the Icebox Formation in southwestern North Dakota. The Roughlock sandstone lithosome is stratigraphically higher than the sandstone lithosome of the Icebox and parts of the two are stacked, one over the other, in a portion of south-central North Dakota. It is possible that these two sandstone lithosomes are genetically related, with the Roughlock lithosome representing a later shift of the deltaic distributaries to the east.

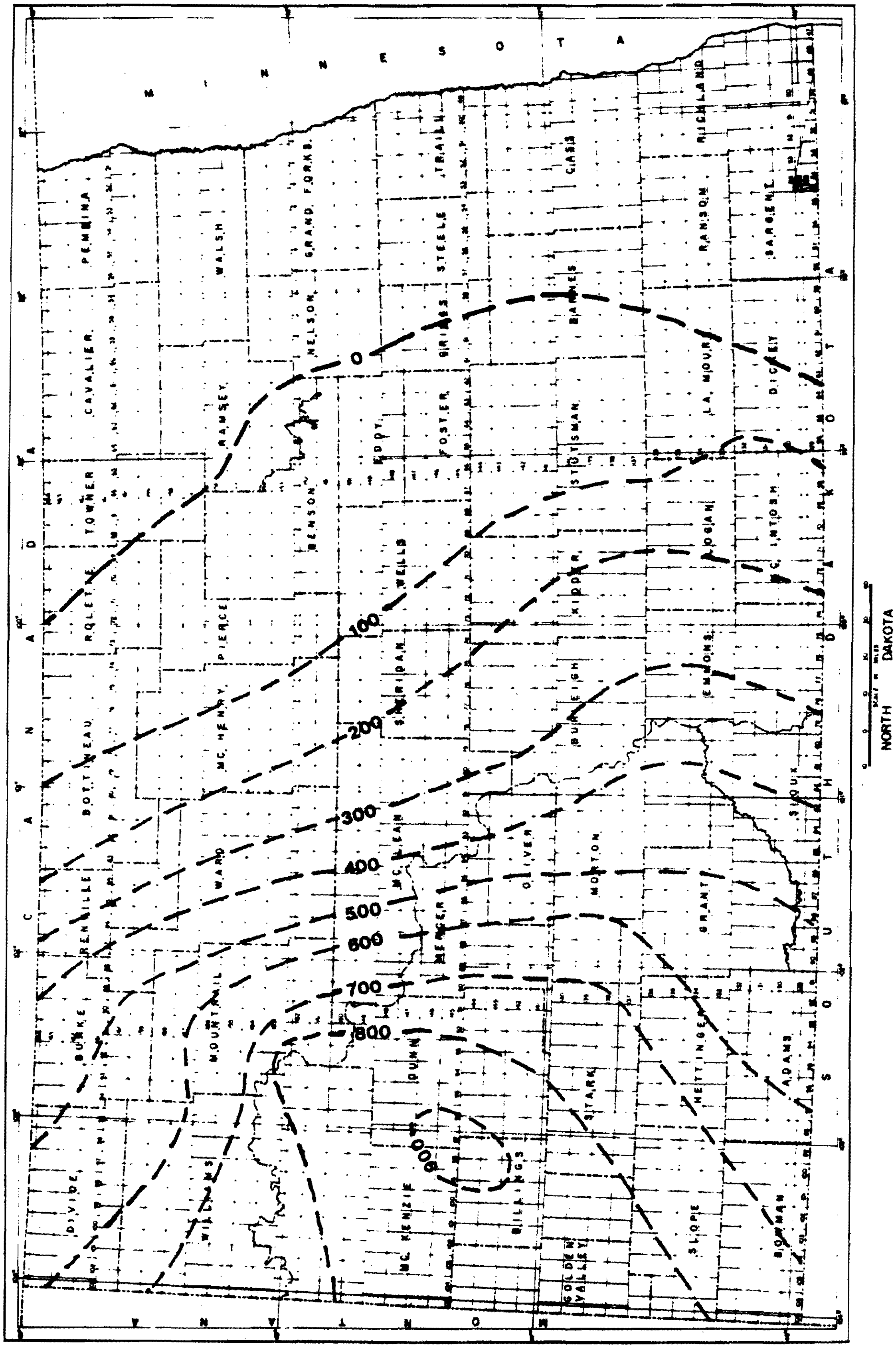
Onset of Williston Basin Subsidence

This study supports the premise that the subsidence of the Williston Basin began during Middle Ordovician time. Gerhard and others (1982, p. 994) suggested that Winnipeg Group sedimentation marked the beginning of the Williston Basin as a discrete structural depression. They also used isopach maps of the Deadwood Formation prepared by Carlson (1960) and Lochman-Balk (1971), which showed a thickening in the center of the basin, to suggest that an embayment extended into North Dakota from the western Cordilleran shelf during latest Cambrian time. This study suggests that this thickening of the Deadwood in the center of the basin may have been largely the result of post-depositional erosion rather than the presence of an embayment at the time of deposition.

Deadwood Formation strata were deposited as part of a craton-wide transgression which began on what is now the west coast of North America in the Late Precambrian. The transgression reached North Dakota in the Late Cambrian and the sea finally retreated during the Early Ordovician. Lochman-Balk (1971, p.82) suggested that broad stable shelves occupied the craton during much of this time. Lochman-Balk (1971) indicated that Cambrian sedimentation on the interior of the craton exhibited the "classical" facies sequence. In general, the Cambrian facies sequence consisted of a sandy shoreline facies which interfingered seaward with a muddy subtidal and shelf facies and which, in turn, interfingered with a carbonate facies farther offshore. Dott and Batten (1981, p. 234) suggested that the rate of transgression of the Cambrian sea must have been very slow and may have been been as little as 10 miles (16 km) per million years. Noting a cyclic vertical repetition of the sandstone, mudstone, and carbonate facies, Lochman-Balk (1971) suggested that the transgression was discontinuous or pulsating, and that small disconformities exist within the Deadwood Formation.

Figure 42 shows an isopach of the Deadwood Formation in North Dakota. Anomalously thin Deadwood sections have been herein ignored so as to smooth out the contour lines. Anomalously thin Deadwood sections, in certain wells, may be the result of Precambrian highs present at the time of deposition. As shown in Figure 42, the Deadwood Formation thins to a feather edge in eastern North Dakota. East of this truncation, Winnipeg strata rest nonconformably on Precambrian crystalline rock. This map also shows that the Deadwood is more than 900 feet (275 m) thick in western North Dakota, with the contours arcing into the state from the west. Gerhard and others (1982, p. 994) used this east-west elongated thick area in eastern Montana and western North Dakota as the

Figure 42. Isopach map of the Deadwood Formation in North Dakota. Contour interval, 100 feet (30.5 m).


MINNESOTA
SOUTH DAKOTA
MONTANA
CANADA
NORTH DAKOTA
PEMBINA
CAVALIER
TOWNER
ROLETTE
BOTTINEAU
RENVILLE
BURKE
DIVIDE
WALSH
RAMSEY
BENSON
PIERCE
MC HENRY
WARD
MOUNTRAIL
WILLIAMS
GRAND FORKS
NELSON
EDDY
WELLS
SHERIDAN
MC LEAN
MERCER
DUNN
MC KENZIE
TRAILL
STEELE
GRIGGS
FOSTER
CASS
BARNES
STUTSMAN
KIDDER
BURLEIGH
OLIVER
MORTON
STARK
BILLINGS
GOLDEN VALLEY
RICHLAND
RANSOM
SARGENT
LA MOURE
DICKEY
LOGAN
MC INTOSH
EMMONS
SIOUX
GRANT
HETTINGER
ADAMS
SLOPE
BOWMAN
0
100
200
300
400
500
600
700
800
900

basis for their interpretation that an embayment extended into North Dakota from the west during the Late Cambrian and Early Ordovician. This study has suggested that the thickening of the Deadwood Formation in the center of the basin may be accentuated by erosion subsequent to deposition rather than being solely due to contemporaneous subsidence and deposition. This alternate interpretation can be best explained with a series of diagramatic cross sections (Figs. 43 and 44). Figure 43 shows Deadwood strata at three instants of time (A_1 the earliest) in cross sections with a west-east orientation. The history of the Deadwood Formation has been simplified here so as to depict what the strata might have looked like had there had been only one major transgression (sandstone followed by shale and then limestone) and one regression (limestone followed by shale and topped by a regressive sandstone). Section A_1-A'_1 represents the Deadwood Formation as it might have appeared soon after the retreat of the Early Ordovician sea to what is now the west. At this time, as suggested by Lochman-Balk (1971), Deadwood sediment probably covered all of North Dakota and extended as far east as Minnesota. By the time represented in section A_2-A'_2 (latest Early Ordovician), erosion had removed Deadwood strata from eastern North Dakota and drainage was probably still to the west over all of North Dakota. Section A_3-A'_3 shows a cross section across North Dakota during the initial stages of the subsidence of the Williston Basin, during the Middle Ordovician. It is probable that the primary source for the Winnipeg that was deposited in the incipient basin was sediment eroded from Deadwood strata at the margins of the subsiding basin. If the Williston Basin did, indeed, first begin to subside during the Middle Ordovician, it follows that the youngest

Figure 43. Diagrammatic cross sections, oriented west-east, of the Deadwood Formation at three instants of time: A1) soon after the withdrawal of the Early Ordovician sea; A2) after erosion had removed some of the Deadwood; and A3) soon after the initiation of Black Island sedimentation.

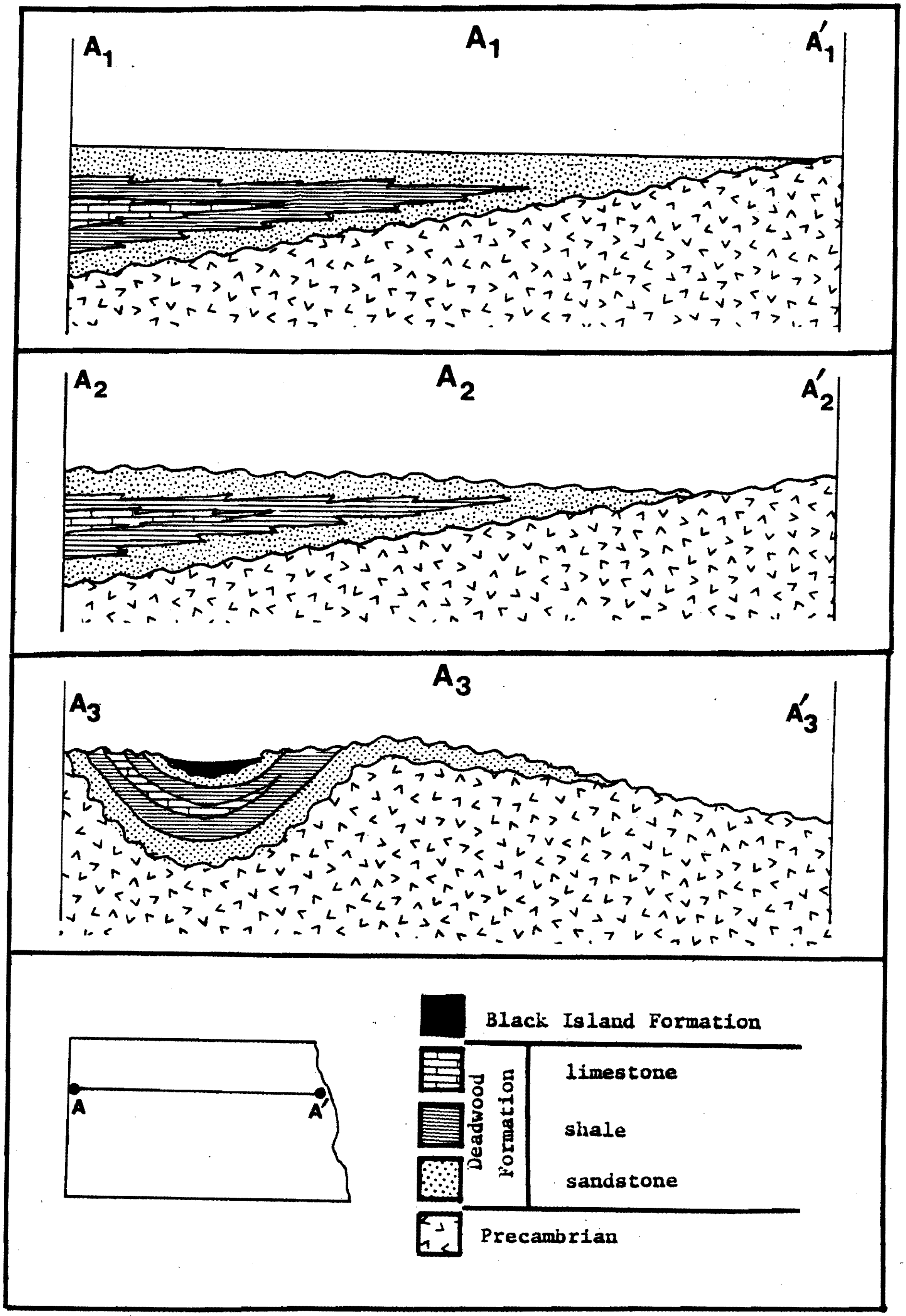
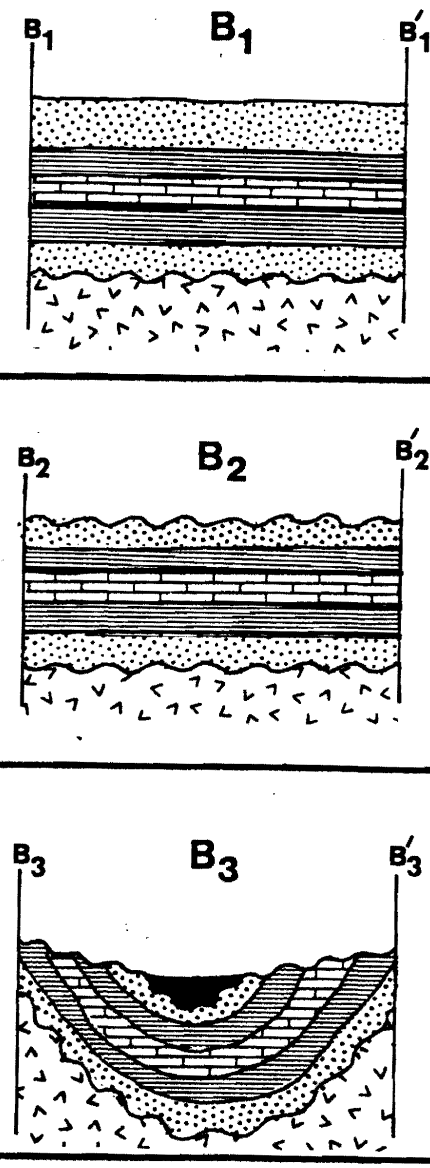
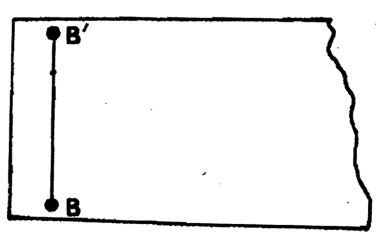

A1
A1
A1'
A2
A2
A2'
A3
A3
A3'
A
A'
Black Island Formation
Deadwood Formation
limestone
shale
sandstone
Precambrian

Figure 44. Diagrammatic cross sections, oriented south-north, of the Deadwood Formation depicting three instants of time: B1) soon after the withdrawal of the Early Ordovician sea; B2) after erosion had removed some of the Deadwood; and B3) soon after the initiation of Black Island sedimentation.





Additional legend given on Figure 45.

Deadwood should be preserved only in the center of the basin because it would have been the first to have been covered and thereby protected by deposition of Black Island strata. As illustrated in section A_3-A'_3 in Figure 43, and in section B_3-B'_3 in Figure 44, the regressive sandstone of the Deadwood was preserved only in the deepest part of the basin while on the margins, the youngest preserved Deadwood strata are limestones.

The three cross sections shown in Figure 44 are of the same ages as the three in Figure 43, but are oriented south-north. They exhibit a similar erosional pattern as that of the sections in Figure 43, with greater erosion from the top of the Deadwood farther away from the center of the basin.

Greater erosion from the top of the Deadwood with increased distance from the central area of Winnipeg deposition is demonstrated in Plate 1. Almost 400 feet (120 m) of Deadwood section is absent from the top of the Deadwood in Adams County, as compared to the Deadwood section in McKenzie County near the present center of the Williston Basin.

The lithology of the Deadwood that directly underlies the Black Island Formation also lends credence to the the hypothesis that greater erosion occurred in Deadwood sections farther from the center of the basin as compared to a Deadwood section closer to the basin's center. At NDGS Well No. 2373, in McKenzie County near the center of the present basin, the uppermost Deadwood strata are sandstones (Fig. 39) and may be regressive in origin. Farther away from the center of the basin, at NDGS Well No. 3268 in southern Billings County, the uppermost Deadwood strata are composed of limestone (Fig. 40). The presence of a limestone as the uppermost Deadwood in Billings County implies that younger shales and sandstones which had previously overlain the limestone have been eroded away. As indicated by the isopach map in Figure 42, the Deadwood becomes very thin in eastern North Dakota. The log responses of the Deadwood in eastern North Dakota (Plate 1, B-B') indicate that the Deadwood in the eastern part of the state is composed largely of sandstone. Section B-B' (Plate 1) shows that "horizon A" marks the uppermost strata of the Deadwood in eastern North Dakota, even though it is stratigraphically quite low in a more complete Deadwood section such as one might find in McKenzie County. The presence of a lower Deadwood sandstone as the uppermost strata of the unit in eastern North Dakota supports the interpretation that the thickest Deadwood section, which is located near the center of the present-day Williston Basin, is the result of subsequent erosion rather than subsidence during deposition.

Middle Ordovician Marine Connection

Evidence gathered in this study suggests that the primary connection of the Middle Ordovician sea to North Dakota was to the southeast, through Minnesota. Such an interpretation implies a break or sag in the Transcontinental Arch along its northeastern portion during the Middle Ordovician. Some geologists studying the Winnipeg in North Dakota have felt the marine connection was probably to the southwest during the Middle Ordovician. Gerhard and others (1982, p. 994) stated that isopach studies suggested a southwesterly connection to the western geosyncline through the present-day central Rockies. However, Carlson (1964, p.49) noted that well data supported a physical continuity between rocks of the Winnipeg Group and the Middle Ordovician section in southeastern Minnesota.

Figure 45 shows a sandstone-shale ratio map of the Winnipeg Group from Foster (1972, p. 81) who published the last significant regional study on the Winnipeg. This map also has isopach contours on it. It may be significant the Winnipeg thins gradually to a feather edge to the west and southwest, but is truncated abruptly to the east and southeast. To the west and southwest, where it thins gradually, the Winnipeg is composed of over 80 percent sandstone. The combination of the gradual thinning and a sandstone lithology suggests that the margins of the Winnipeg to the west and southwest are depositional in nature. In contrast, where the group is truncated to the east and southeast, the Winnipeg is composed of 60-80 percent shale. The Winnipeg is probably nowhere near its depositional limit in southeastern North Dakota. The combination of truncated isopach contour lines and a high percentage of shale at the east and southeast erosional limit suggests that the Winnipeg originally extended considerably farther to the southeast. The above information tends to support a marine connection to the southeast.

Information presented by Parham and Austin (1967) also supports a southeastern marine connection for the Winnipeg in North Dakota. Parham and Austin (1967) mapped variations in the relative abundance of kaolinite and illite in the clay-size fraction of the Glenwood Formation of southeastern Minnesota and adjacent portions of neighboring states (Fig. 46). The St. Peter is the basal deposit of the Middle Ordovician transgression which also deposited the Black Island Formation. The Glenwood Formation, composed predominantly of shale, overlies the St. Peter Sandstone and may be the physical equivalent of the Icebox Formation. Parham (1966) was able to show that lateral variations in mineral assemblages can be used to show directions of sediment transport

Figure 45. Sandstone-shale ratio map of the Winnipeg Group in North Dakota and surrounding states (from Foster, 1971, p. 81).

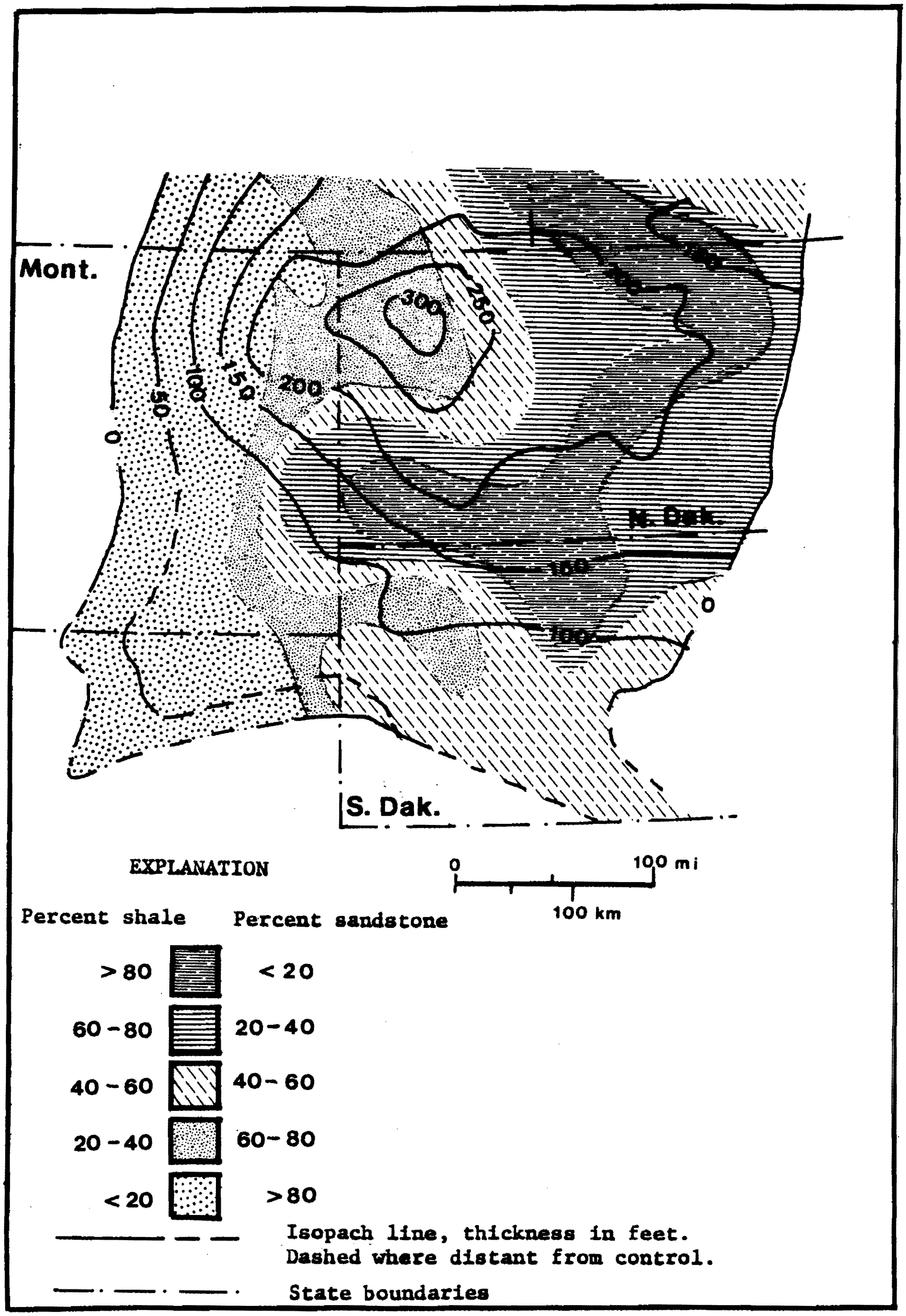
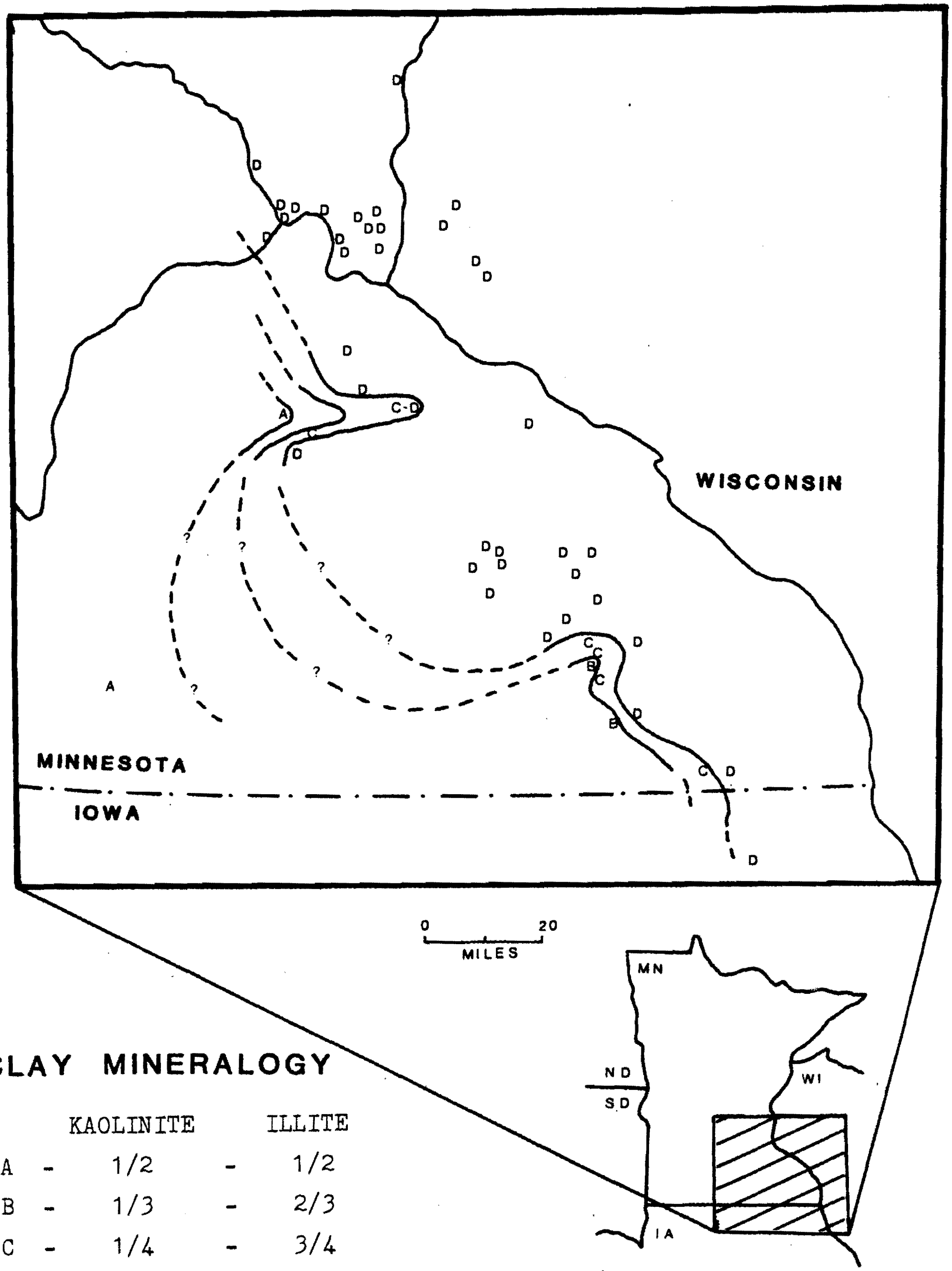

Mont.
N. Dak.
S. Dak.
0
50
100
150
200
250
300
100
0
100
0
100 mi
100 km
EXPLANATION
Percent shale
Percent sandstone
>80
<20
60-80
20-40
40-60
40-60
20-40
60-80
<20
>80
Isopach line, thickness in feet.
Dashed where distant from control.
State boundaries

Figure 46. Kaolinite-illite ratio map of the Glenwood Formation in southeastern Minnesota (after Parham and Austin, 1967).



CLAY MINERALOGY

	KAOLINITE	ILLITE
A -	1/2 -	1/2
B -	1/3 -	2/3
C -	1/4 -	3/4
D -	0 -	1

in both modern and ancient rocks. Parham (1966, p. 143) indicated that kaolinite can be expected to be found more shoreward than illite. In Figure 46, the letters "A" mark locations with the lowest ratios of kaolinite while those marked "D" denote locations where no kaolinite was found within the Glenwood Formation. Parham and Austin (1967) used this kaolinite to illite ratio map (Fig. 46) to suggest a southwest source for the Glenwood Formation in southeastern Minnesota. The map trend of the highest illite ratios on their map (Fig. 46) extends northwest-southeast. This trend supports the hypothesis that the Transcontinental Arch may not have been a continuous high through Minnesota during the Middle Ordovician as had been implied by some geologists (Witzke, 1980; Dott and Batten, 1981). Had the Transcontinental Arch extended unbroken from southwestern to northeastern Minnesota, one might have expected the trend of the highest illite ratio (offshore) to have been oriented parallel to the arch rather than perpendicular to it. The northwest-southeast "offshore trend" suggests that the Transcontinental Arch may not have been a continuous positive feature in Minnesota in the Middle Ordovician. Extension of the offshore trend of the Glenwood Formation (Fig. 46) meets the southwest termination of Winnipeg shown in Figure 45 and further supports the interpretation that a a southeast marine connection to North Dakota existed during the Middle Ordovician.

Depositional History

Information gathered about the Winnipeg Group in this study has been integrated into a depositional history. Several concepts are important for an understanding of the sequence of Winnipeg Group sedimentation. First, it is assumed that deposition of the formations of the Winnipeg Group was time-transgressive in nature. This assumption was not without some substantiation. Other basal units of craton-wide transgressions are thought to be time-transgressive, including the St. Peter Sandstone (Middle Ordovician) of the upper Mississippi Valley and the Tapeats Sandstone (Cambrian) of the southwestern United States. The Roughlock has been demonstrated to be physically continuous from the Black Hills to eastern North Dakota (Clarence G. Carlson, written communication, 1984) and has also been shown to be considerably younger in eastern North Dakota than in the Black Hills (Walter C. Sweet, written communication, 1984). Different ages in different localities for the Roughlock indicates that it is time-transgressive in nature. It has also been suggested (Fuller, 1961; Carlson, 1964) that the Black Island is time-transgressive -- that it is older in the Williston Basin than in outcrop near Lake Winnipeg, Manitoba.

Another concept important to the understanding of the depositional history of the Winnipeg Group is the nature of the facies relationships between its lithostratigraphic units. The contacts between the formations of the Winnipeg Group all appear to be gradational, and intertonguing appears to have occurred between the lower and upper members of the Black Island Formation and between the upper member of the Black Island and the Icebox Formation. The presence of intertonguing is strong evidence for the existence of a facies relationship between the units involved. Although the Icebox and the Roughlock do not appear to intertongue, it is here interpreted that the two formations are transitional one to the other and are facies of each other. The Roughlock and the lower part of the Red River Formation are also interpreted to be, at least in part, facies of each other.

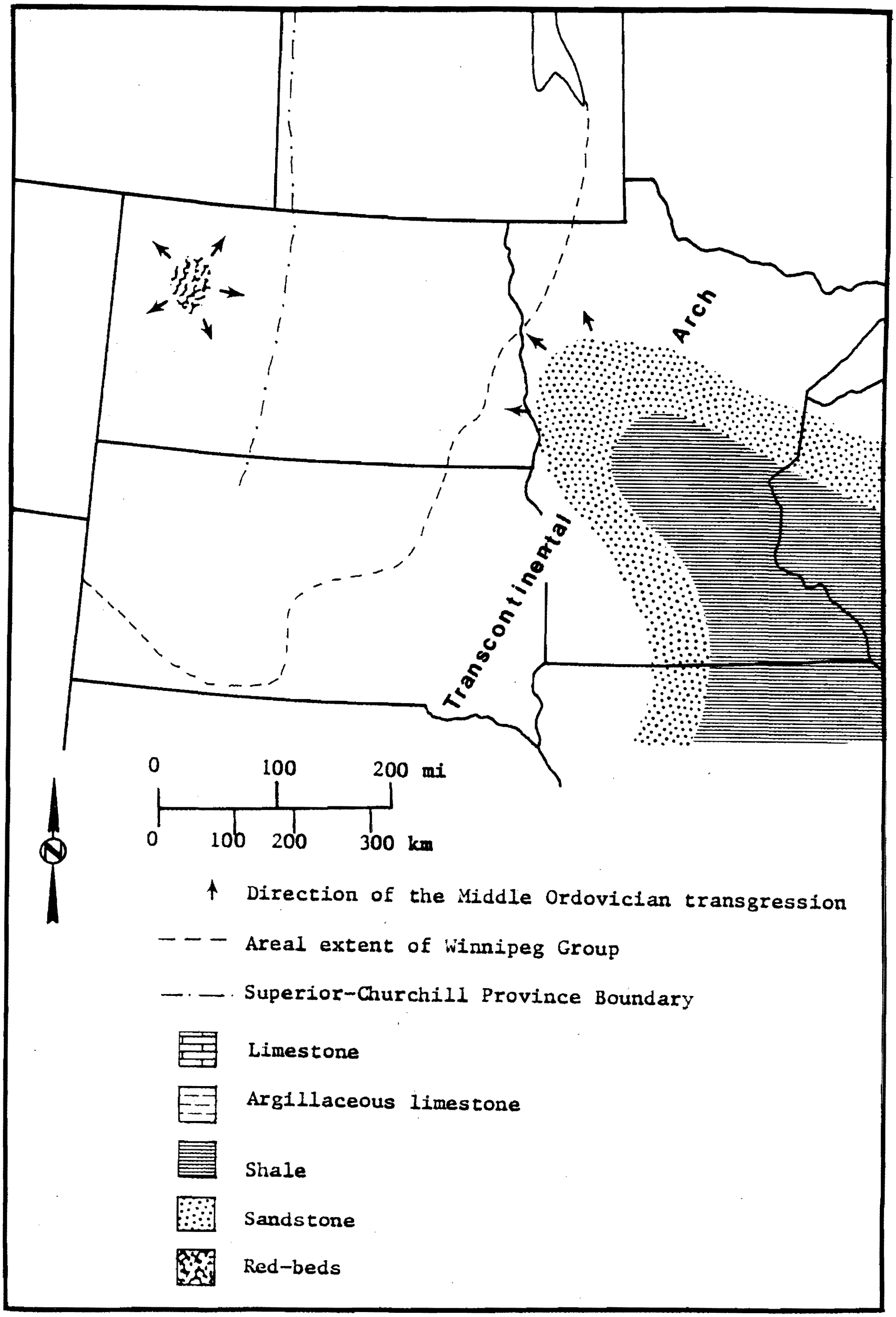
Other information included in the interpretation of the depositional history is the possible presence of a slight structural high along the location of the Churchill-Superior Province boundary. This high is suggested by the presence of a north-south trending thin zone on the Icebox isopach map (Fig. 26). Another aspect to be considered is the suggested southeasterly marine connection to North Dakota during Middle Ordovician time. These features suggest that forces which initiated the subsidence of the Williston Basin uplifted the area along the Churchill-Superior Province boundary and may thus have also altered the paleoslope. The isolated, circular pattern of the isopach contours of the lower member of the Black Island suggests that drainage into the newly forming Williston Basin may have had a centripetal pattern. The large areal extent of the lower Black Island deltaic plain deposits also suggests that deposition of this unit began before the transgressing Middle Ordovician sea had reached North Dakota. The combination of a structural high along the Churchill-Superior Province boundary and a later, southeasterly, marine connection suggests a divide along this boundary causing drainage east of the boundary to have been to the southeast during earliest Winnipeg deposition.

The depositional history of the Winnipeg Group can be best explained using diagrammatic sketches showing the paleogeography at successive stages in the deposition of the Winnipeg in North Dakota. Because the depositional history of the Winnipeg in North Dakota is so closely tied to that of the surrounding states and provinces, regional paleogeographic interpretations are also included.

The initial deposits of the Winnipeg Group were the deltaic plain deposits of the lower member of the Black Island Formation, with deposition beginning in the northwestern North Dakota (Fig. 47). As shown by the isopach map of this unit (Fig. 13), the lower member of the Black Island attains a thickness of over 100 feet (30 m) in the central area of deposition. The thick accumulation of these continental deposits suggests that the rate of sedimentation kept pace with subsidence so that there was not a large enough volume of open water to create a beach environment in the early Williston Basin. The roughly circular pattern of the isopach contours (Fig. 13) suggests that drainage into this incipient basin may have been centripetal and that the lower member of the Black Island expanded radially, as indicated by the arrows on Figure 47.

Evidence presented in this study suggests that the main marine connection of the Winnipeg Group in North Dakota was to the southeast. This implies a break or sag in the Transcontinental Arch in central Minnesota during the Middle Ordovician. The dashed line on Figure 47 represents the present-day areal extent of Middle Ordovician rocks in North Dakota and portions of the surrounding states and provinces. The Middle Ordovician in North Dakota, South Dakota, Manitoba, and Saskatchewan consists of the rocks of the Winnipeg Group. The Middle Ordovician in southeastern Minnesota is represented by the St. Peter Sandstone and the Glenwood Shale. Both the upper member of the Black Island and the St. Peter are the basal deposits of the Middle Ordovician transgression. Prior to erosion along the Transcontinental Arch, these two sandstone units were probably physically continuous. As interpreted in Figure 47, subsidence was beginning in the Williston Basin with the deposition of the lower member of the Black Island as the general marine transgression was advancing from the southeast. As suggested by

Figure 47. Generalized interpretation of the regional paleogeography and environmental setting at the time of the initiation of Williston Basin subsidence.


Arch
Transcontinental
0
100
200 mi
0
100
200
300 km
Direction of the Middle Ordovician transgression
Areal extent of Winnipeg Group
Superior-Churchill Province Boundary
Limestone
Argillaceous limestone
Shale
Sandstone
Red-beds

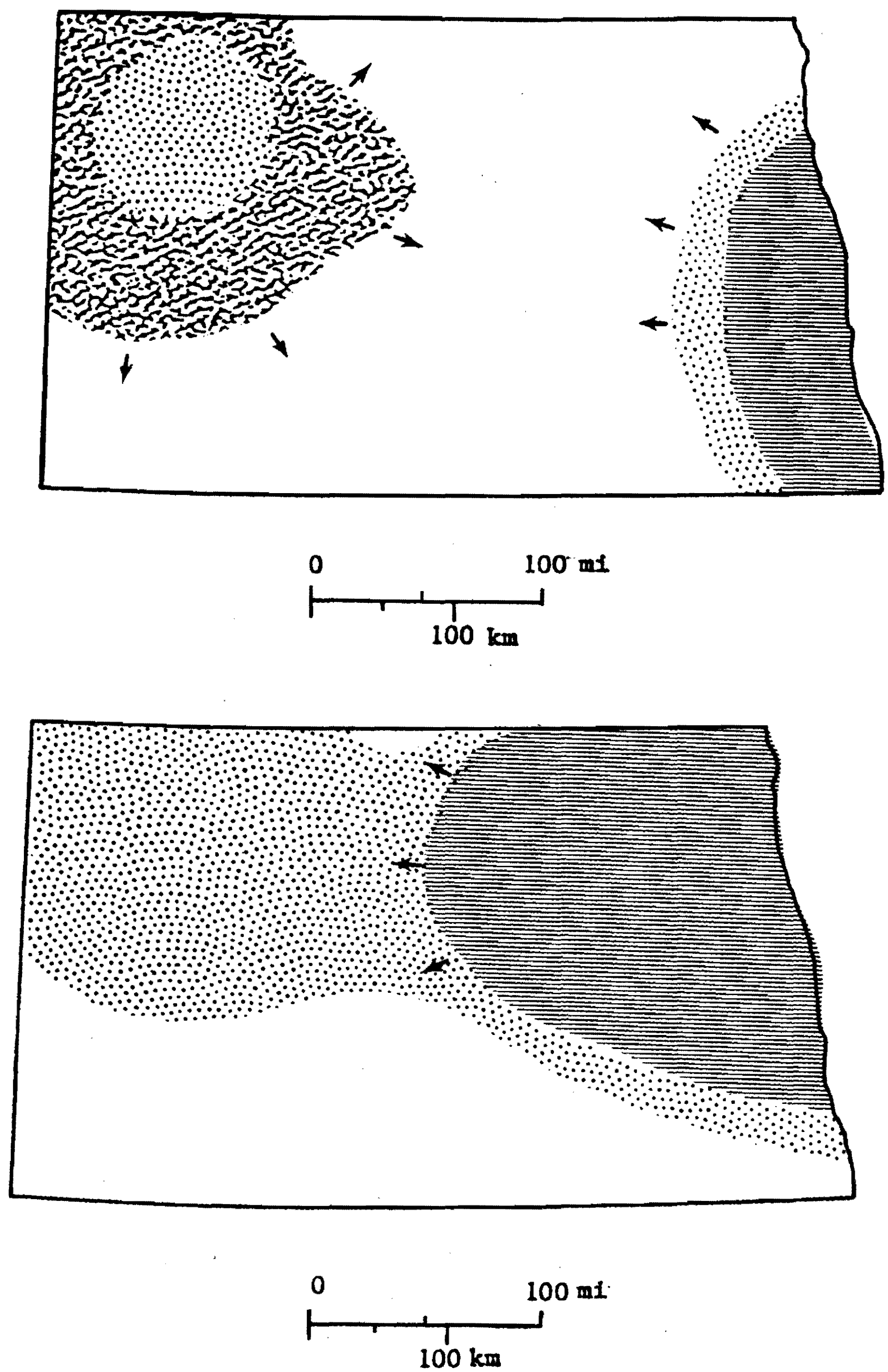
Ojakangas and Matsch (1982, p. 79), in southeastern Minnesota the beach and nearshore deposits of the St. Peter are overlain by the shale of the Glenwood Formation which was deposited farther offshore.

By the time depicted in Figure 48, the Williston Basin had subsided rapidly enough to accumulate a substantial standing body of water, as evidenced by the nearshore deposits of upper member of the Black Island. As in the case of the lower member, the upper member of the Black Island is thickest over the area of the present Nesson Anticline; this implies that the area of the Nesson Anticline continued to be the locus of maximum subsidence. Thick accumulation of the sandstone of the upper member of the Black Island suggests that much of the early Williston Basin remained at or near wave base. The high energy of the water acted to winnow out the silt- and clay-sized particles. The upper member of the Black Island exhibits concentric isopach contours as does the lower member. As the basin continued to subside, the deposits of the upper member expanded out from the center of the basin and onlapped the older sediments of the lower member of the Black Island. The green quartz wacke lithofacies of both the lower and upper members of the Black Island have been interpreted to have been the initial deposits of the Middle Ordovician transgression. The presence of this lithofacies in both the lower member and the lower part of the upper member of the Black Island may represent intertonguing between the two members. The position of the transgressive deposits of the green quartz wacke lithofacies between the nearshore deposits of the upper member of the Black Island suggests that the Middle Ordovician transgression occurred in pulses, and was probably not a continuous event.

The general transgression of the Middle Ordovician sea continued

Figure 48. Williston Basin when enough subsidence had occurred to permit sandstones of the upper member of the Black Island Formation to accumulate in the center of the Basin. (Explanation on Figure 47).

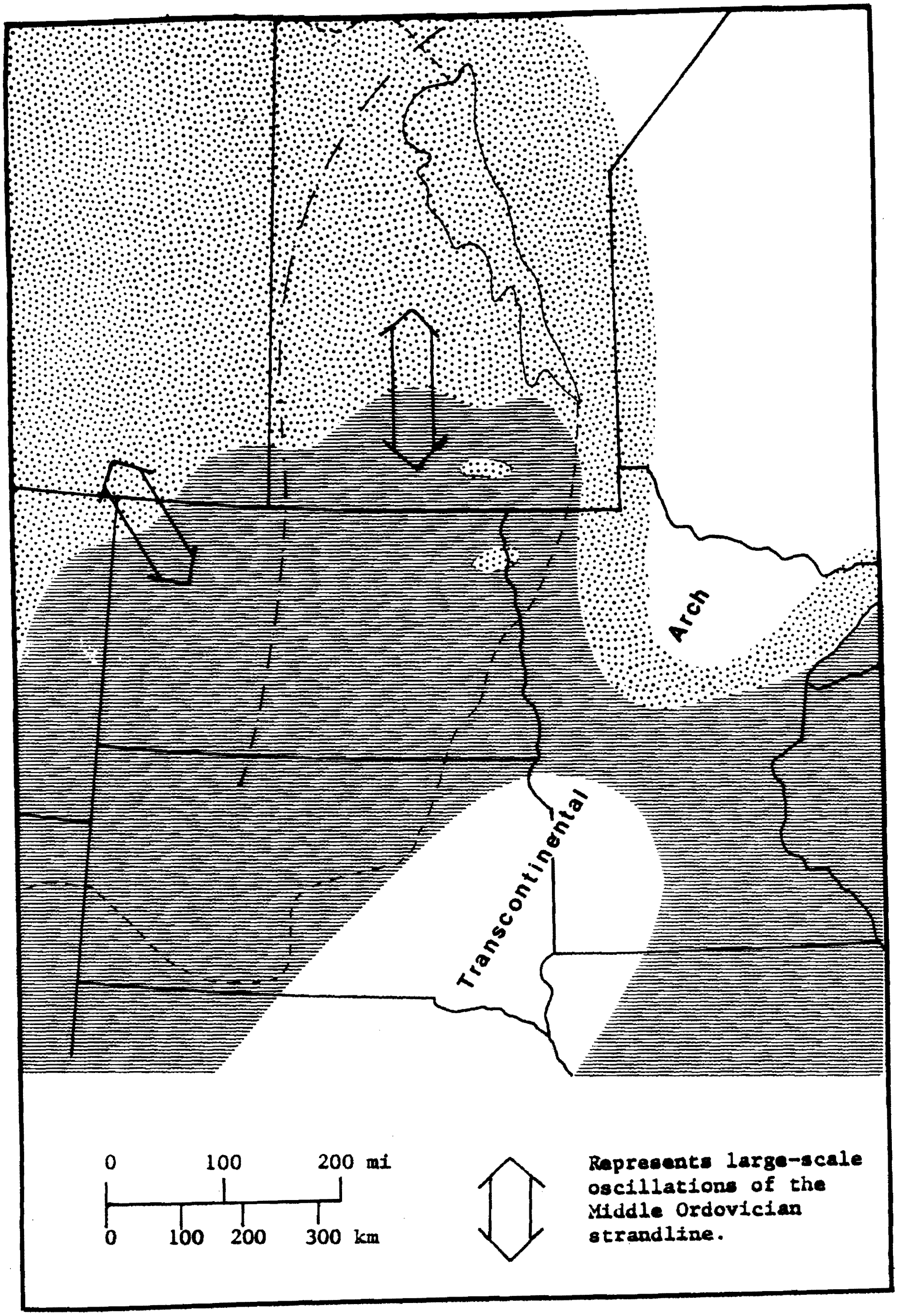
Figure 49. Connection of Middle Ordovician transgression with the waters from the subsiding Williston Basin. (Explanation on Figure 47).


0
100 mi
100 km
0
100 mi
100 km

from the east until it finally joined the water body and contained deposits of the Williston Basin (Fig. 49). The thinness of the upper member of the Black Island Formation in eastern North Dakota (Fig. 22) suggests either that the transgression over the eastern part of the state was a relatively rapid event or that subsidence in this part of the state was mimimal. Water in the western third of the state probably remained relatively shallow for a considerable length of time even after it was connected to the main part of the continental epeiric sea. The thick accumulation of sandstone and the scarcity of shale within the upper Black Island in western North Dakota suggests that sedimentation kept pace with subsidence and thus that the substrate was at or near wave base for an extended period of time. The presence of conodonts in the upper member attests to the marine environment.

By the time diagrammed in Figure 50, the general Middle Ordovician transgression had advanced to a stage where all of North Dakota had been inundated, the Deadwood had been covered, and deposition of the sand of the Black Island had ceased in North Dakota. The water was deep and calm enough, with the source of sand far enough removed, to deposit the clay of the Icebox Formation over most of North Dakota. Over much of Manitoba and Saskatchewan, the Winnipeg is composed mostly of sandstone interbedded with smaller amounts of shale (Vigrass, 1971; McCabe, 1978). The Winnipeg in Manitoba has been interpreted to have been deposited on a large, shallow shelf (Vigrass, 1971). Minor fluctuations in the sea level could have resulted in a large variation in the position of the shoreline and the sandstone lithosome within the Icebox Formation in northwestern North Dakota may have been the result of one of these fluctuations, where nearshore deposits temporarily retreated basinward

Figure 50. Generalized interpretation of the regional and environmental setting at the time when shales of the Icebox Formation were deposited over most of North Dakota and portions of Manitoba and Saskatchewan. (Explanation on Figure 47).

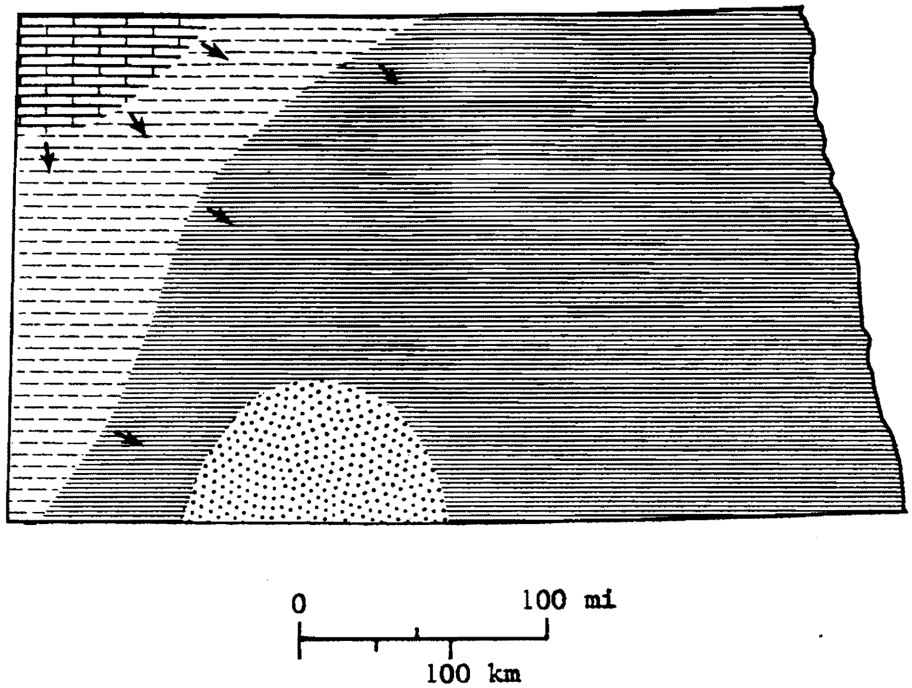

Arch
Transcontinental
0 100 200 mi
0 100 200 300 km
Represents large-scale oscillations of the Middle Ordovician strandline.

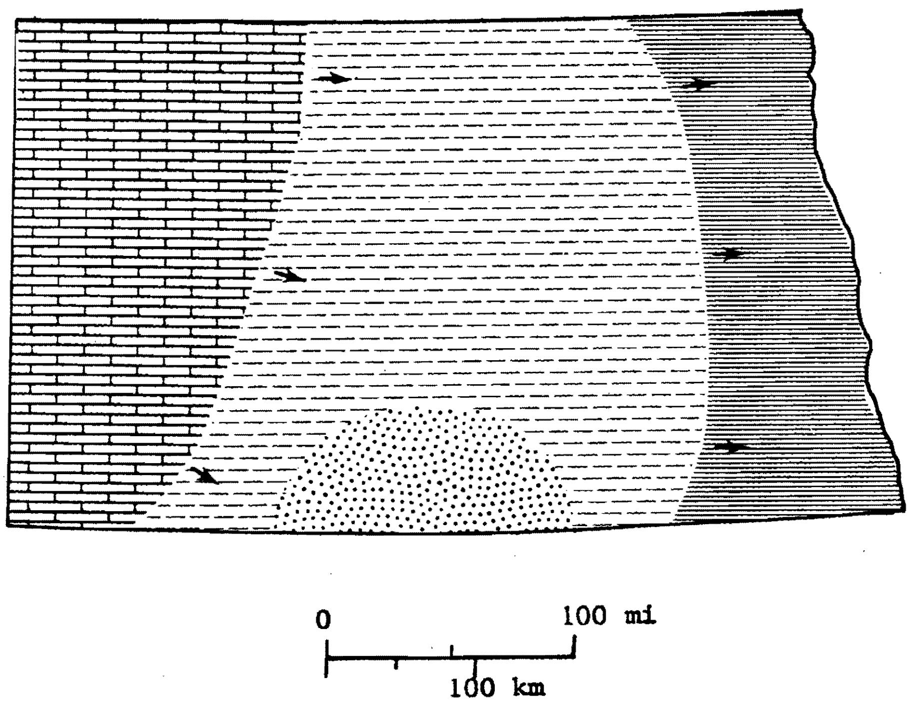
as far as Divide County, North Dakota. The elongate sand body within the shale of the Icebox Formation in Grand Forks County is probably similar in origin to the sandstone body in southern Manitoba, which has been interpreted to be an offshore bar (Vigrass, 1971, p. 232).

Eventually, the general Middle Ordovician transgression advanced far enough to cover broad portions of the Canadian Shield, the Transcontinental Arch, and possibly other previously exposed areas that are now north and west of North Dakota. With source areas removed farther from North Dakota, the amount of detrital material reaching the state must have become reduced; and, with the reduction in clastic sedimentation, conditions became more favorable for the production of carbonates. Western North Dakota, which was located the farthest from sources of Middle Ordovician detritus, was the first area to become free enough of clastic material to permit transition from the noncalcareous shale of the Icebox Formation to the argillaceous limestone of the Roughlock Formation. In northwestern North Dakota, the transition must have occurred very rapidly, as there is virtually no Roughlock present (Fig. 51) and the Red River Formation was deposited directly upon the clayshales of the Icebox. As illustrated in Figure 51, the Icebox, Roughlock, and the lower part of the Red River were, at least in part, facies of each other. The vertical, gradational contacts between these formations, which can be viewed in cores, are suggestive of the relationships between these formations as facies at the time of deposition. It is interpreted here that sediments of the Icebox, Roughlock, and part of the Red River Formations were transitional from one to the next and, at least in part, graded into each other laterally (i.e., were facies of each other). Over most of the state, the Icebox

Figure 51. Initiation of deposition of limestone of the Red River Formation in western North Dakota. The Roughlock is transitional in lithology and facies position between the Icebox and the Red River Formations. (Explanation on Figure 47).

Figure 52. Advancement of the three facies (Icebox, Roughlock, and Red River Formations) to the east. (Explanation on Figure 47).


0
100 mi
100 km


0
100 mi
100 km

is separated from the Red River by the argillaceous limestone of the Roughlock Formation. Given that each of these three units was a facies of the others, the units were contemporaneous, as suggested in Figure 52. As indicated by the arrows, all of the facies migrated toward what is now the east through time, as the sea expanded in all directions.

A large sandstone body extends into North Dakota from the south within the Roughlock Formation (Fig. 52). Much of the Roughlock in South Dakota may be composed of siltstone or sandstone (Clarence G. Carlson, oral communication, 1984) and the Roughlock is a siltstone at the type area in the northern Black Hills. The coarser nature of the Roughlock to the south may be due to its closer proximity to a source area in that direction.

Eventually, transgression of the sea continued until all sources of terrigenous clastics in the area had been covered. With the removal of clastics, the carbonates of the Red River Formation were able to onlap the Winnipeg over all of North Dakota (Fig. 53). Figure 54 shows a paleogeographic reconstruction of North America during the Late Ordovician. As shown here, the Taconian highlands were the only exposed surface in the United States. Dott and Batten (1981, p. 260) suggested that the North American Late Ordovician epeiric sea represented one of the most complete floods experienced by any continent. The equator was located close to the area of North Dakota; conditions were thus ideal for carbonate production.

Figure 53. Red River Formation at a stage when Winnipeg Group strata had been onlapped over all of North Dakota. (Explanation on Figure 47).

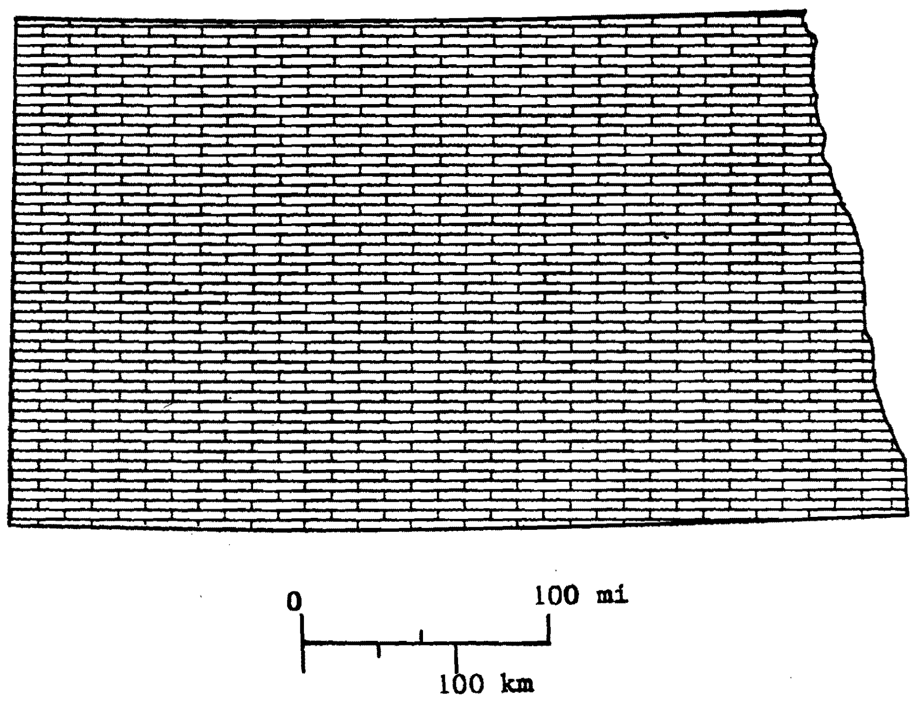
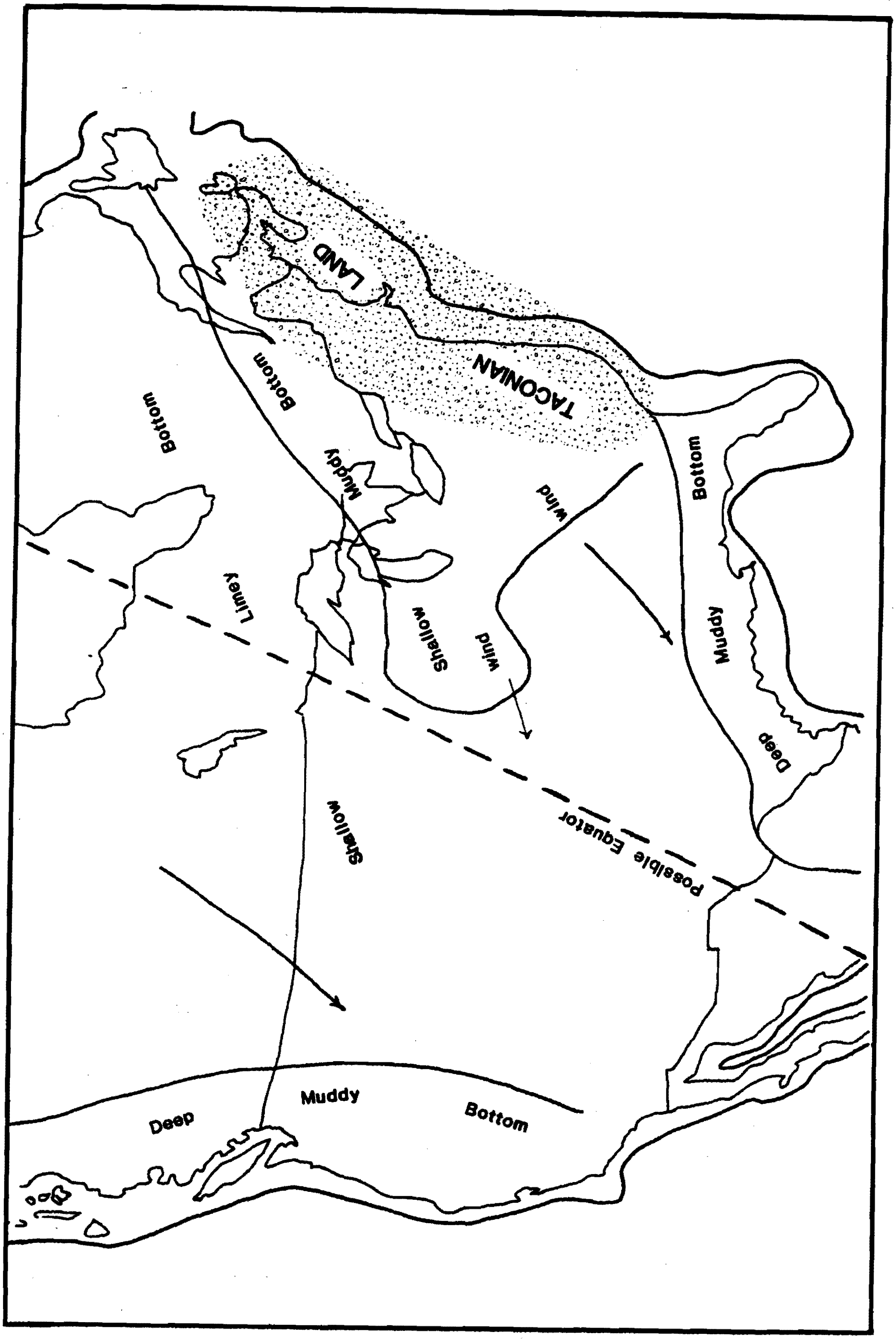

0
100 mi
100 km

Figure 54. Generalized interpretation of Late Ordovician paleogeography of the United States (after Dott and Batten, 1981).


TACONIAN
LAND
Muddy Bottom
Limey Bottom
Shallow
wind
wind
Deep Muddy Bottom
Possible Equator
Shallow
Deep Muddy Bottom

CONCLUSIONS

1. The strata of the Winnipeg Group are divided into three formations: the Black Island Formation, the Icebox Formation, and the Roughlock Formation. Each of these is lithologically distinct, mappable in the subsurface, and can be traced to the outcrop area from which the formations have been named.

2. The location of the boundary between the Deadwood Formation and the Black Island is herein redefined. In the center of the basin, the boundary between the two formations was heretofore placed above sandstone and shale beds near the base of the Black Island. Correlation of well logs shows that large-scale truncation of beds occurs beneath these sandstone and shale beds, suggesting that the boundary is located beneath the sandstone and shale. Based on the above, the sandstone and shale beds at the base of the Black Island are here informally called the lower member of the Black Island.

3. The lower member of the Black Island is reddish brown, hematite-cemented, quartz arenite and clayshale, and these lithologies and their associations suggest that their deposition occurred under continental conditions on a deltaic plain environment.

4. The upper member of the Black Island Formation is structureless quartz arenite and bioturbated quartz wacke and is interpreted to have been deposited in an inner-shelf environment. The thickness of this unit indicates either very slow subsidence of the Williston Basin, or a high rate of clastic input, or both, at the time of deposition.

5. Greenish gray clayshale of the Icebox Formation was deposited

in a middle-shelf environment. The existence of a facies relationship between the upper member of the Black Island and the Icebox is supported by the presence of a possible tongue of the upper member of the Black Island in the clayshale of Icebox Formation in Divide County.

6. The Roughlock Formation is argillaceous, nodular limestone and is also interpreted to have been deposited in a middle-shelf environment. Rocks of the Roughlock appear to represent a lithologic transition between the noncalcareous clayshale of the Icebox and the limestone of the overlying Red River Formation and are partial facies of both the Icebox Formation and the lower part of the Red River Formation.

7. The dominant diagenetic feature of the sandstone of the lower member of the Black Island is hematite cement which, in places, has replaced quartz overgrowths. Secondary diagenetic features of the lower Black Island include calcite and anhydrite cement. The sandstones of the upper Black Island have either a clay matrix or quartz overgrowths. Clay coatings on some of the detrital quartz grains appear to have inhibited the formation of quartz overgrowths.

8. The Deadwood Formation is thickest near the center of the present day Williston Basin. This study suggests that the reason that the Deadwood is thickest in the center of the basin is, at least partially, due to erosion of the Deadwood on the sides of the basin during the time of the deposition of the Winnipeg, rather than solely due to subsidence at the time of deposition. The subsidence of the Williston Basin may have begun during Middle Ordovician time, coincident with the deposition of the Winnipeg Group.

9. The main marine connection of the seas that deposited the Winnipeg Group may have been to the southeast rather than to the southwest as has been suggested previously. A southeast marine connection implies a break or sag in the northeastern portion of the Transcontinental Arch during Middle Ordovician time.

10. Although oil and gas production has been limited to only a few wells to date, the Black Island may be, in some areas, an attractive target for petroleum exploration. The Black Island contains all the criteria necessary for hydrocarbon accumulation: a reservoir rock, a source rock, and a cap rock. The Black Island has, in places, high porosity and is everywhere capped by the relatively impermeable clayshale of the Icebox Formation. The Icebox is also a possible source rock for Black Island accumulations (Dow, 1974). The Black Island may serve, in the future, as a profitable secondary horizon for the production of petroleum or natural gas.

11. Suggestions for possible future studies include a more complete diagenetic investigation of Winnipeg Group strata, a regional study of the Deadwood Formation, and a study of the paleontology and biostratigraphy of the formations of the Winnipeg Group.

APPENDICES

APPENDIX A. Name and Location of Wells From Which Well Logs Were Studied

North Dakota Geological Survey Well Number, Location (Township North, Range West, Section, and Quarter Section), Original Operator and Well Name (from records of North Dakota Geological Survey).

NDGS WELL NO.	LOCATION		OPERATOR/ WELL NAME
ADAMS COUNTY			
6322	130-91-7	NESW	ENERGETICS INC SOELBERG #23-7
7642	130-95-28	NWSE	AMOCO PROD. CO. JACOB CHRISTMAN #1
BARNES COUNTY			
4640	140-59-9	SESW	J M JOHNSTON ET AL ALLAN E VIG#1
BENSON COUNTY			
632	154-70-31	NWSE	CALVERT DRILLING CO AUTHUR J & IDA J & GINA STADUM #1
BILLINGS COUNTY			
291	139-100-9	NWNE	AMERADA PETROLEUM CORP HERMAN MAY U #1
3268	139-101-10	NESW	AMERADA PETROLEUM CORP SCORIA UNIT #8
6228	144-98-3	NWSW	GULF OIL CORP ZABOLOTNY #1-3-4-A
6303	143-100-29	NESW	TENNECO OIL CO BN #1-29
6913	143-99-9	SENW	AMOCO PROD. CO. THOMPSON #1
7307	143-99-22	SENE	AMOCO PROD. CO. KNUDTSON STATE #1
7520	143-99-21	NENE	AMOCO PROD. CO. H.T. KNUDTSON #1
7934	142-100-23	SWNW	W.H. HUNT TRUST ESTATE ANNA OSADCHUK B-1
8226	143-100-27	NWSW	COASTAL OIL & GAS CORP & HUNT ENERGY 27-143-100 HLEBECHUK ET AL #1
8487	143-102-13	SESE	CONOCO, INC. BLACKTAIL #13-1
8603	142-98-31	SWSE	ADOBE OIL AND GAS CORPORATION STATE KORDONOWY #34-31

NDGS WELL NO.	LOCATION		OPERATOR/ WELL NAME
BOTTINEAU COUNTY			
38	160-81-31	SWSE	CALIFORNIA OIL CO BLANCHE THOMPSON #1
64	163-77-18	SWNW	HUNT OIL OLIVER OLSON #1
110	163-75-23	NWNW	LION OIL HUSS #1
2219	161-79-6	SESW	CALIFORNIA OIL CO BERT HENRY #4
4655	162-78-31	SESW	AMERADA PETROLEUM CORP H D LILLESTRAND #1
4790	159-81-20	SESE	UNION OIL CO OF CALIF ABRA STEEN #1
4846	163-81-8	NENW	LAMAR HUNT W CRANSTON #1
5184	162-77-14	SENE	CHAMPLIN PET CO DUNBAR #1 42-14
BOWMAN COUNTY			
485	129-104-16	NWNW	WILLIAM HERBERT HUNT ZACH BROOKS-STATE #1
1575	129-106-9	NWSW	CARTER OIL CO LEWIS L & ELLEN JOHNSON #1
BURKE COUNTY			
8893	162-89-8	SWSW	MONSANTO COMPANY MELBY #1
BURLEIGH COUNTY			
19	140-77-6	SESE	CONTINENTAL-PURE, DAVIDSON STRATIGRAPHIC TEST
151	140-80-18	SWSW	HUNT OIL EMMA KLEVEN
174	140-77-3	NWNW	CONTINENTAL DUENELAND #1
701	144-75-36	NENE	CAROLINE HUNT TRUST ESTATE BOARD OF UNIV &SCHOOL LANDS #1
723	139-76-36	NENE	CAROLINE HUNT TRUST ESTATE R P SCHLABACH #1
756	137-77-32	SESE	CAROLINE HUNT TRUST ESTATE R A NICHOLSON #1
763	144-77-14	SESE	CAROLINE HUNT TRUST ESTATE ANTON NOVY #1
765	142-76-31	SWSW	CAROLINE HUNT TRUST ESTATE SODER INVESTMENT CO #1
772	140-79-23	NWNW	CAROLINE HUNT TRUST ESTATE PAUL RYBERG #1
1409	140-77-11	NWSE	LEACH OIL & CALVERT PATTERSON LAND CO #1
6264	139-76-9	NENE	TOM F MARSH FUNSTON #1

NDGS WELL NO.	LOCATION		OPERATOR/ WELL NAME
7010	138-78-31	NENE	ASAMERA OIL (U.S.) INC. WELCH #1
8674	141-76-17	SWSW	SUN OIL COMPANY T. D. THORSON #1
CAVALIER COUNTY			
1694	162-63-10	NWNW	JOHNSON OIL EARL MOORE #1
2342	160-57-3	NWSW	FRED TRAUGNOTT GOODMAN ESTATE #1
DICKEY COUNTY			
682	130-63-34	SESE	SNOWDEN CHESTER L GIBSON #1
1394	129-66-22	NWNW	CALVERT DRILLING CO MARVIN KAMM
DIVIDE COUNTY			
1546	162-101-34	NENW	KERR MCGEE CORP ARLET JOHNSON
2010	163-102-7	NWNE	CARTER OIL CO DALLAS D MOORE #1
6798	162-96-16	NESE	SHELL OIL CO. RINDEL #43-16
7087	163-95-18	SESW	SHELL OIL CO. SVANGSTU #24-18
7660	163-97-24	SWSW	PATRICK PETR. CORP. VAALER #1-24
7942	160-97-19	NWSE	W.H. HUNT TRUST ESTATE LEONARD ROSTEN #1
8498	162-101-22	NWNW	SOUTHLAND ROYALTY COMPANY GERALD RAAUM #1-22
8707	161-95-25	SENW	HOME PETROLEUM CORPORATION KJELSHUS #2
9677	164-98-33	SESW	TEXACO INC. R. L. HANSON #1
DUNN COUNTY			
6086	145-94-7	NENE	AMOCO PROD CO BERENT SELLE #1
6148	141-96-2	SWSW	AMOCO PROD CO ANDREW M HEISER #1
6530	141-95-18	SENE	AMOCO PROD. CO. WOLBERG #1
7402	144-91-9	SWNE	MOSBACHER PRUET OIL CO. NEUROHR #9-1
7412	145-93-18	SWNW	CITIES SERVICE CO. STATE OF ND #A-1
7584	145-95-8	NENW	AMOCO PROD. CO. ROSHAU #1
8077	147-96-10	NESW	MESA PETROLEUM COMPANY PELTON #1-10

NDGS WELL NO.	LOCATION		OPERATOR/ WELL NAME
8536	144-93-7	SWSE	TERRA RESOURCES, INC. KLING #1-7
8536	144-93-7	SWSE	TERRA RESOURCES, INC. KLING #1-7
8613	144-93-20	SWSW	EXXON CORPORATION ADOLF GEIST #1
8709	147-93-8	NESW	SHELL OIL COMPANY BURBANK BIA #23-8
8768	145-92-30	NWNW	TERRA RESOURCES, INC. WERNER #1-30
9027	144-92-31	SESW	LUFF EXPLORATION CO. GELLER N-31
9044	146-93-11	SENW	ANR PRODUCTION CO. HANSEN #1-11A
EDDY COUNTY			
437	150-67-16	NWNW	CALVERT DRILLING CO N DAK STATE #1
768	150-65-8	NENE	CALVERT DRILLING CO #1 STATE #1
EMMONS COUNTY			
16	133-75-35	NWSW	NORTHER ORDINANCE FRANKLIN INVESTMENT CO #1
23	133-76-35	NESE	ROESSER & PENDELTON J J WEBER #1
43	132-78-8	NESE	PEAK DRILLING OLHAUSER #1
7101	132-76-10	SWSW	KELDON OIL CO. HORNER #1
7146	136-75-15	NWNE	CHEVRON U.S.A., INC. NAADEN #1
7936	136-75-13	NWNW	CHEVRON U.S.A. INC. RASSEN RAMBOUGH #1
FOSTER COUNTY			
295	145-62-26	SWNE	T M EVANS BAILEY #1
334	145-64-24	NENE	T M EVANS CHRISTIAN ERICKSON #1
403	146-66-15	NENE	PURE OIL J M CARR #1
1105	146-65-8	SESW	CARDINAL, KAUFMAN, GREAT PLAINS ET A J S SMITH #1
1112	146-66-23	NENE	CARDINAL, KAUFMAN, GREAT PLAINS ET A N A GRAVES&FEDERAL LAND BANK#1
1126	146-67-10	NWNW	CARDINAL DRLG. CO ET AL J M ANDERSON #1
1227	147-64-25	NENE	MIKE WETCH H F SPICKLER #1-A

NDGS WELL NO.	LOCATION		OPERATOR/ WELL NAME
GOLDEN VALLEY COUNTY			
410	143-103-24	NESW	GULF OIL CORP DOROUGH FEDERAL #1
470	140-105-15	NESE	BLACKWOOD & NICHOLS GILMAN & LANG #1
6272	137-106-22	NWNW	SHELL OIL CO KREMERS #21-22
6513	141-104-31	NENE	SHELL OIL CO DAVIDSON #41-31
6563	139-105-4	NWNE	SHELL OIL CO. SMITH #31-4
7753	141-104-7	SENE	MORAN EXPLORATION, INC. KUNICK #1
8590	144-103-28	SENW	IKE LOVELADY, INC. MOORE-FEDERAL #1-28
9148	139-105-16	NENE	HUNT OIL COMPANY KIPPLEY-STATE #1-16
GRAND FORKS COUNTY			
580	151-53-15	NENE	A J SCOTT A J SCOTT #1
1356	152-54-24	SWSE	NORTH PLAINS PET INC F F DANNER #1
3191	153-52-5	NWSW	CANADIAN-DAKOTA SASTEX DENNIS WOSICK #1-A
3204	152-51-17	NWNW	CANADIAN-DAKOTA SASTEX JULIAN NERESEN ESTATE #1
GRANT COUNTY			
5572	132-86-27	NENW	GAS PROD ENT INC BURL NO #1
6420	132-86-7	SWSW	MARSHALL R YOUNG OIL CO 7-132-86-BN #1
6586	134-90-17	NWNE	THE ANSCHUTZ CORP. FRED ALT #1
7020	137-88-5	SENE	TEXAS PACIFIC OIL CO. WILLIAM STECKLER #1
8549	134-87-16	SESE	SHELL OIL COMPANY HIRNING-STATE #44-16
8680	131-88-35	NENW	SHELL OIL COMPANY BN #21-35
HETTINGER COUNTY			
7075	133-93-26	SWSE	AMOCO PROD. CO. ROKUSEK #1
7453	133-97-24	SESW	AMOCO PROD. CO. URLACHER #1
8312	135-96-35	NWSW	SKYLINE OIL COMPANY FEDERAL HERBERHOLZ 35 #1

NDGS WELL NO.	LOCATION		OPERATOR/ WELL NAME
LOGAN COUNTY			
590	136-73-6	NWNE	CAROLINE HUNT TRUST ESTATE F M FULLER #1
1347	136-71-25	NWNW	CALVERT, LEACH, INTERNATION, WESTERN RAY CRAIG #1
5523	135-73-29	NWNW	WISER OIL CO NO 2ET AL BALTZER A WEIGEL #1
MC HENRY COUNTY			
39	157-78-3	NESW	HUNT OIL W B SHOEMAKER #1
61	153-77-17	NWSE	HUNT OIL PETER LENNERTZ #1
8307	155-77-31	NENW	ASAMERA OIL (U.S.) INC. LARSON #1
8803	151-80-22	NENE	ATLANTIC RICHFIELD COMPANY WUNDERLICH #1
MC INTOSH COUNTY			
89	131-73-15	NENE	GENERAL ATLAS CARBON A KETTERLING #1
620	130-69-13	NESE	CALVERT DRILLING CO C C NITSCHKE #1
621	130-69-19	NWNW	CALVERT DRILLING CO JOHN BENDER #1
622	131-69-17	SWNW	CALVERT DRILLING CO KARL SCHOCK #1
MC KENZIE COUNTY			
2373	152-95-1	NESE	AMERADA PETROLEUM CORP ANTELOPE-DEV U #8
6387	148-104-6	SWSE	SHELL OIL CO USA #34X-6
6414	148-104-8	NENW	SHELL OIL CO US GOVT #21-8
7001	154-95-34	NWSW	TEXACO INC. & AMERADA RED RIVER UNIT 1 #1
7203	149-99-14	NWSE	AMOCO PROD. CO. WILBUR CAMPBELL #1
7571	151-95-31	SWNE	TEXACO INC. REITSCH NCT-2 #4
7631	151-99-33	NENE	TEXACO INC. HENRY TORSTENSON #1
7988	153-95-5	NWSW	TEXACO, INC. RED RIVER UNIT 2 #1
8090	152-95-6	NESE	AMERADA HESS CORPORATION GRIMISTAD #4-6
8092	151-99-27	SWNE	TEXACO INC. R. T. LATTIN #1
8131	151-99-10	SWSW	TEXACO, INC. C.L. STENBERG "A" #1

NDGS WELL NO.	LOCATION		OPERATOR/ WELL NAME
8165	151-101-23	SENE	SUNBEHM GAS, INC. SKEDSVOLD #1
8187	148-101-10	NWNE	W. H. HUNT TRUST ESTATE LARSON #1
8193	146-102-3	SENW	PENNZOIL COMPANY & DEPCO COVERED BRIDGE #3-22
8268	151-102-13	NENE	AL-AQUITAINE EXPLORATION, LTD. THURLOW #1-13
8302	149-101-24	NWSE	TRAVERSE OIL COMPANY NYGAARD #1-24
8314	147-103-8	SENE	SHELL OIL COMPANY USA #42-8
8626	152-98-17	SWNE	PATRICK PETROLEUM COMPANY ENDERUD #1-17
9004	150-100-10	NESE	EXXON CORPORATION FLECK #1
MCLEAN COUNTY			
22	146-81-10	SWNE	SAMEDAN OIL CORP VAUGHN HANSON #1
49	150-80-28	SWSW	STANOLIND MCCLEAN COUNTY #1
7783	150-90-1	SENW	HOME PETR. CORP. TRIBAL #1-1
8060	148-89-7	SWNE	APACHE CORP. SOLCUM #1
8711	146-80-31	SESE	SUN OIL COMPANY FLEMMER #1
8720	144-81-34	NENE	SUN OIL COMPANY FAHLGREN #1
8993	149-80-26	NWNW	ATLANTIC RICHFIELD CO. KLAIN #1
MERCER COUNTY			
21	142-89-28	NWNE	KELLY-PLYMOUTH FRITZ LEUTZ #1
8675	142-90-6	NENW	MGF OIL CORPORATION ENTZE #21-6
8712	145-90-29	SWSW	GULF OIL CORPORATION ISAAK #1-29-4D
MORTON COUNTY			
26	136-81-29	NENW	PHILLIPS-CARTER DAKOTA #1
1620	139-90-27	NESW	PAN AMERICAN PET CORP RAYMOND YETTER #1
3859	135-83-34	SENE	AMERADA PETROLEUM CORP JAMES MEYER #1
7340	140-88-26	NWSE	AMOCO PROD. CO. RICHTER #1
7691	138-85-19	SENW	AMOCO PROD. CO. OLIN #1

NDGS WELL NO.	LOCATION		OPERATOR/ WELL NAME
7797	137-87-14	SESE	TEXAS PACIFIC OIL CO. BACHLER #1
7937	138-86-19	NENE	AMOCO PROD. CO. OLSEN #1
8158	138-82-6	SWSE	PENZOIL COMPANY SWEET BRIAR #6-34
8553	140-82-17	SENW	SHELL OIL COMPANY VOGEL #22-27
MOUNTRAIL COUNTY			
6780	151-89-24	SENE	BASS ENTERPR. PROD. CO. ROBERT ANDES #24-1
6872	153-88-16	NESE	MARATHON OIL CO. MAE OLSON #1
NELSON COUNTY			
1934	152-60-5	SESE	REELFOOT DEV CO INC L & A BRYL #1
4664	151-61-32	NWSW	JACK M JOHNSTON DRILLING CO SYDNEY L HAAS #1
4785	151-60-6	NENE	JACK M JOHNSTON DRILLING CO GRITZ #1
OLIVER COUNTY			
8144	141-82-15	SESE	PENNZOIL CO. LITTLE BOOT #15-44
PEMBINA COUNTY			
700	164-56-28	NESE	TURNER OIL THEODORE BEIANUS #1
PIERCE COUNTY			
435	158-69-12	SENW	MIDWEST OIL CORP HECKMAN #1
706	157-70-23	SESE	SHELL OIL CO GIFFORD MARCHUS #1
3920	152-74-23	SESE	A J HODGES IND INC ALEX MARTIN #1
5576	152-73-34	SWSW	GETTY OIL LUDWIG VETTER #1
RAMSEY COUNTY			
20	158-62-29	CNE	UNION OIL COMPANY AANSTAD NO.1
196	154-65-16	NENE	CARTER OIL COMPANY ALLAN MACDIARMID #1
407	153-63-13	NESW	CALVERT EXPLORATION COMPANY CARL JACK #1
4745	156-62-14	NWSW	JOHN R. BLACK ESTATE CECIL J. MILLER #1
4914	156-61-32	NENE	MILLER & FOX DRILLING CORP. ERWIN LORENZ #1

NDGS WELL NO.	LOCATION		OPERATOR/ WELL NAME
RENVILLE COUNTY			
6505	162-87-33	SESW	FULTON PROD. CO. JENSEN #24-33
6624	161-85-1	SENW	SHELL OIL CO. OSTERBERG #22X-1
6684	161-85-2	NENW	SHELL OIL CO. OSTERBERG #21-2
7577	160-86-15	SWNW	SHELL OIL CO. DEWING #12-15
ROLETTE COUNTY			
316	160-70-23	NWSW	EVANS PRODUCTION CORPORATION ANDY LEROY JOHNSON #1
SHERIDAN COUNTY			
665	148-76-15	NENE	CAROLINE HUNT TRUST ESTATE JOHN WALTZ JR #1
684	147-75-1	NENE	CAROLINE HUNT TRUST ESTATE J R MATZ #1
693	146-76-19	SWSW	CAROLINE HUNT TRUST ESTATE WALTER E BAUER #1
735	146-74-16	SWSW	CAROLINE HUNT TRUST ESTATE C A PFEIFFER #1
SIOUX COUNTY			
631	131-80-29	NESW	OHIO OIL COMPANY STANDING ROCK SIOUX TRIBE #1
SLOPE COUNTY			
8629	136-98-34	SENE	COBRA OIL AND GAS CORP. STATE SMITH #34-1
9244	136-98-2	NWSE	WILLIAM C. KIRKWOOD EHLIS #32-2
STARK COUNTY			
6447	139-97-8	SWNW	ANADARKO PROD CO KOSTELECKY #1
8088	141-93-28	NWNE	MOBIL OIL CORPORATION WILLIAM BERNHARDT #1
8169	138-92-21	NENW	GULF OIL CORP. LEVIATHAN #1-21-1B
8342	140-95-36	NWNW	SUPRON ENERGY CORPORATION LAWRENCE #1
8665	137-92-4	NESW	GULF OIL CORPORATION KILZER #1-4-4B
9056	139-93-24	SENW	GULF OIL CORP. OGRE #1-24-1C
9135	138-91-28	SENE	PIONEER PRODUCTION CORP. DIEDE #1-28
9256	139-93-14	NWSE	GULF OIL CORPORATION HUTCHINSON 1-14-3A

NDGS WELL NO.	LOCATION		OPERATOR/ WELL NAME
9257	139-92-19	NESW	GULF OIL CORPORATION HAMANN #1-19-4B
9322	139-96-29	SESE	WILLIAM C. KIRKWOOD KOSTELECKY #44-29
9341	139-93-10	NESW	GULF OIL CORP. MOORE #1-10-4B
9348	139-92-30	NWSE	EXXON CORP. HAMMON #1
9407	139-92-32	NESW	GULF OIL CORP. HOFF 1-32-4B
9684	138-97-34	NENW	MOBIL OIL CORP. J. F. FISHER #1
STUTSMAN COUNTY			
120	142-63-21	SENW	GENERAL ATLAS CARBON CO. A PEPLINSKI #1
134	142-65-15	SWNE	GENERAL ATLAS CARBON CO. F BORTHEL #1
406	140-65-20	NENE	HERMON HANSON OIL SYNDICATE M M MUELLER #2
644	139-68-5	SESE	GORDON B. BUTTERFIELD RUDOLPH TRAUTMAN #1
668	137-67-25	SESW	CALVERT EXPL. CO. MARGARET MEYERS #1
669	139-68-35	SESW	CALVERT EXPL. CO. CHRIST RAV #1
670	139-67-24	SESW	CALVERT EXPL. CO. D C WOOD #1
671	140-67-12	NWSW	CALVERT EXPL. CO. GEORGE GANSER #1
TOWNER COUNTY			
100	161-68-35	SWSE	UNION OIL COMPANY OF CALIFORNIA ARNE SAARI NUMBER ONE
171	163-65-18	NWNE	F H RHODES HAROLD MURPHY #1
194	157-65-17	SWSE	F H RHODES R R GIBBENS #1
227	158-66-31	SESW	EARL F WAKEFIELD EDNA LOUISE HILL #1
390	160-67-24	SWSE	MIDWEST EXPLORATION CORP H ANANN #1
434	163-68-27	NWNW	MIDWEST EXPLORATION COMPANY INC HENRY P JUTENEN #1
3980	162-68-7	SWSE	LA HABANA CORP. & NAT'L ASSOC. PETR.
WALSH COUNTY			
2623	156-58-9	NENW	TRAUGOTT DRILLING HATTIE BAKKE #1
2973	156-56-8	SWSE	I J WILHITE-CANADIAN DAKOTA DEV A O GAARDER #1

NDGS WELL NO.	LOCATION		OPERATOR/ WELL NAME
WARD COUNTY			
47	155-81-23	SESW	WILLIAM HERBERT HUNT TRUST ESTATE JOE H & ANNA WALD #1
105	153-85-2	SWNE	STANALIND WALTER & INGEBERG WASWICK #1
588	152-82-33	SWSE	WILLIAM HERBERT HUNT F C NEUMANN #1
7612	155-87-15	SESW	MARATHON OIL CO. BERG #15-24
WELLS COUNTY			
207	146-73-27	SESE	CONTINENTAL OIL COMPANY JOHN LUETH NUMBER ONE
609	148-71-14	SWSE	CAROLINE HUNT TRUST ESTATE GEORGE LEITNER #1
642	150-70-32	NWNE	CAROLINE HUNT TRUST ESTATE OBED LARSON #1
WILLIAMS COUNTY			
1231	155-96-2	SENE	AMERADA PETROLEUM CORP IVERSON + NELSON U #1
1385	156-95-16	SESW	AMERADA PETROLEUM CORP N.D. "A" U #9
1403	155-96-15	SWNE	AMERADA PETROLEUM CORP BOE-OLSON #1
1514	156-96-34	SENE	AMERADA PETROLEUM CORP ULVEN UNIT #1
1636	156-95-17	SESW	AMERADA PETROLEUM CORP PETERSON DEVIDSON U #1
4321	158-95-36	NWSW	AMERADA PETROLEUM CORP N.D. "C" B #9
4323	158-95-26	NESW	AMERADA PETROLEUM CORP HJALMER IVES #B-1
4618	156-103-17	NENW	AMERADA PETROLEUM CORP NILS TROGSTAD #1
4716	155-96-11	SENW	AMERADA PETROLEUM CORP B L O U #4
5069	156-96-36	SENW	AMERADA PETROLEUM CORP B L O U #5
5577	157-95-29	NENW	TIGER OIL CO NELSON #21-29
5725	157-95-20	SESE	TIGER OIL CO BIWER #44-20
5937	157-95-30	SENE	TIGER OIL CO. SCHMIDT #42-30
6098	154-95-3	SENE	TIGER OIL CO HOVE #42-3
6478	155-100-5	SWSW	LAMAR HUNT SHAIDE-FLB #1
7931	155-97-33	SESW	MAPCO INC. NCGA #14-33

NDGS WELL NO.	LOCATION	OPERATOR/ WELL NAME
8316	159-102-18 SWSE	DEPCO, INC. FISCHER #34-18
8692	159-99-30 SWNE	TEXAS GAS EXPLORATION CORP. SOGARD #1-30
9100	159-100-11 NWSW	TEXAS GAS EXPLORATION CORP. ESTERBY #1-11

APPENDIX B. Formation and Member Tops

Depths in feet from Kelly Bushing; ROUGHLK = Roughlock Formation; ICEBX = Icebox Formation; UPPER BLACK ISLAND = upper member of the Black Island Formation; LOWER BLK ISLAND = lower member of the Black Island Formation; DDWD = Deadwood Formation; PC = Precambrian; and - = missing data.

NDGS WELL NO.	ROUGHLK	ICEBX	UPPER BLK ISLAND	LOWER BLK ISLAND	DDWD	PC
ADAMS COUNTY						
6322	8855	8893	-	-	8990	9400
7642	9660	9683	-	-	9777	-
BARNES COUNTY						
4640	1692	1778	1913	-	1928	1945
BENSON COUNTY						
632	4857	4917	5050	-	5090	5142
BILLINGS COUNTY						
291	12801	12809	12925	12954	12959	-
3268	12483	12487	12598	12626	12631	13509
6228	14135	14150	14282	14332	14359	15265
6303	13396	13402	13516	13552	13569	14224
6913	14082	14094	14214	14257	14272	-
7307	14100	14110	14228	14269	14278	-
7520	14058	14064	14186	14228	14236	-
7934	13438	13444	13554	13592	13603	14389
8226	13563	13572	13688	-	13739	-
8487	13049	13060	13172	13205	13227	-
8603	13437	13439	13553	13589	13598	-
BOTTINEAU COUNTY						
38	7835	7860	7970	8040	8050	8246
64	6156	6172	6295	-	6337	6407
110	6211	6225	6351	-	6382	6424
2219	6948	6968	7086	-	7138	7258
4655	6470	6482	6590	-	-	6608
4790	7910	7930	8042	-	8118	-
4846	7226	7240	7354	-	7422	7553
5184	6119	6141	6253	-	6305	6360
BOWMAN COUNTY						
485	9697	9710	-	-	9800	-
1575	8732	8745	-	-	8839	-

NDGS WELL NO.	ROUGHLK	ICEBX	UPPER BLK ISLAND	LOWER BLK ISLAND	DDWD	PC
BURKE COUNTY						
8893	10419	10433	10547	10642	10673	10915
BURLEIGH COUNTY						
19	6488	6538	6665	-	6685	6947
151	7560	7601	7725	-	7735	8088
174	6400	6452	6575	-	6596	6858
701	6022	6070	6198	-	6218	-
723	5628	5689	5818	-	5833	-
756	5905	5972	6112	-	6129	-
763	6517	6563	6686	-	6710	-
765	6517	6563	6686	-	6710	-
772	7010	7055	7181	-	7204	-
1409	6327	6380	6505	-	6528	-
6264	5889	5944	6071	-	6092	6300
7010	6280	6341	6467	-	6478	6750
8674	6251	6299	6425	-	6445	6700
CAVALIER COUNTY						
1694	3189	3228	3343	-	3365	3365
2342	2137	2185	2287	-	2312	2312
DICKEY COUNTY						
682	1670	1733	-	-	-	-
1394	2880	2940	-	-	3060	3147
DIVIDE COUNTY						
1546	11604	11615	11740	-	-	-
2010	10822	10822	10968	-	-	-
6798	11656	11656	11787	11894	11908	12350
7087	11055	11062	11188	11287	11300	11783
7660	11091	11091	11218	-	-	-
7942	12755	12770	12905	13023	13056	13624
8498	11310	11318	11439	-	-	-
8707	12576	12587	12717	-	-	-
9677	10919	10919	11050	11142	11148	-
DUNN COUNTY						
6086	13915	13933	14058	14110	14185	-
6148	13262	13275	13393	13432	13440	-
6530	13100	13110	13230	13270	13280	-
7402	12560	12578	12716	12760	12805	-
7412	13673	13678	13818	-	-	-
7584	14161	14176	14310	14362	14426	-
8077	14578	14595	14736	14801	-	-
8536	13452	13465	13598	-	-	-
8536	13452	13465	13598	-	-	-
8613	13531	13550	13676	13730	13796	-
8709	14083	14103	14238	14306	14357	-
8768	13441	13468	13597	-	-	-
9027	13021	13041	13170	13213	13275	-
9044	13805	13822	13957	14017	14071	-

NDGS WELL NO.	ROUGHLK	ICEBX	UPPER BLK ISLAND	LOWER BLK ISLAND	DDWD	PC
EDDY COUNTY						
437	3900	3968	4101	-	4128	4223
768	3562	3622	3761	-	3783	-
EMMONS COUNTY						
16	4860	4932	5054	-	5062	5350
23	5048	5105	5242	-	5245	-
43	5348	5403	5531	-	5540	5851
7101	4900	4950	5083	-	5090	5394
7146	5094	5173	5300	-	5315	5592
7936	5064	5145	5270	-	5282	-
FOSTER COUNTY						
295	2582	2655	2787	-	2803	2862
334	2989	3065	3193	-	3212	3289
403	3373	3434	-	-	3560	3560
1105	3223	3391	3518	-	3522	-
1112	3498	3567	3700	-	3710	3791
1126	3850	3913	-	-	-	-
1227	2980	3054	-	-	3187	3271
GOLDEN VALLEY COUNTY						
410	12988	13007	13115	13153	13165	-
470	12268	12277	12380	12409	12414	-
6272	10962	10962	11063	-	11080	11493
6513	12371	12380	12482	12506	12520	-
6563	11978	11987	12085	-	12118	-
7753	12407	12425	12524	12549	-	-
8590	12793	12797	12930	-	12995	-
9148	11900	11909	12007	-	12038	-
GRAND FORKS COUNTY						
580	637	731	888	-	-	895
1356	791	882	1049	-	-	1060
3191	561	655	775	-	-	792
3204	320	410	-	-	-	-
GRANT COUNTY						
5572	7740	7790	-	-	7902	-
6420	8024	8072	-	-	8190	-
6586	9679	9716	-	-	9848	10424
7020	10176	10197	10317	-	10328	-
8549	8753	8794	-	-	8904	-
8680	8123	8172	-	-	8283	8817
HETTINGER COUNTY						
7075	10028	10059	10165	-	10168	10725
7453	10585	10593	10699	-	10707	11193
8312	11008	11027	11130	-	11149	-

NDGS WELL NO.	ROUGHLK	ICEBX	UPPER BLK ISLAND	LOWER BLK ISLAND	DDWD	PC
LOGAN COUNTY						
590	4878	4963	5088	-	5095	-
1347	4123	4210	4332	-	4351	4550
5523	4802	4878	5005	-	5010	-
MC HENRY COUNTY						
39	6872	6900	7019	-	7096	7203
61	6946	6972	7097	-	7167	-
8307	6900	6935	7053	-	7108	-
8803	8333	8350	8468	8532	8540	-
MC INTOSH COUNTY						
89	4373	4427	-	-	4560	4772
620	3255	3308	3448	-	3460	3590
621	3450	3495	-	-	3650	3828
622	3560	3627	-	-	3767	3924
MC KENZIE COUNTY						
2373	13788	13818	13963	14120	14224	15120
6387	13306	13343	13452	13497	13505	-
6414	13330	13367	13472	13540	13550	-
7001	13477	13507	13658	-	-	-
7203	14527	14557	14680	-	-	-
7571	14438	14463	14611	14741	14848	-
7631	14387	14417	14535	14591	14653	-
7988	13586	13613	13760	13920	14008	-
8090	14180	14207	14359	14513	14622	-
8092	14736	14760	14912	-	-	-
8131	14910	14946	15076	15143	15225	-
8165	14003	14030	14149	14198	14243	-
8187	14210	14247	14357	14406	14443	-
8193	13410	13447	13559	-	-	-
8268	13874	13901	14017	-	-	-
8302	14223	14258	14372	-	-	-
8314	13337	13377	13488	13530	13560	14420
8626	15026	15055	15190	-	-	-
9004	14535	14570	-	-	-	-
MCLEAN COUNTY						
22	8750	8780	8895	-	8930	-
49	8640	8662	8780	8840	8865	-
7783	13257	13280	13410	13525	13578	14240
8060	12891	12912	13040	13143	13190	-
8711	8385	8415	8530	-	8573	8843
8720	8158	8191	8309	-	8356	8659
8993	8366	8408	8527	8577	8610	-
MERCER COUNTY						
21	11867	11880	12010	-	12078	-
8675	12188	12204	12327	12369	12390	-
8712	12800	12821	12947	13000	13056	-

NDGS WELL NO.	ROUGHLK	ICEBX	UPPER BLK ISLAND	LOWER BLK ISLAND	DDWD	PC
MORTON COUNTY						
26	7122	7188	-	-	7316	7758
1620	11018	11032	11162	-	11183	-
3859	7562	7621	-	-	7743	8194
7340	10531	10542	10675	-	10713	-
7691	9158	9198	9312	-	9323	-
7797	9581	9606	-	-	9733	-
7937	9202	9218	-	-	9334	9691
8158	7794	7838	7958	-	7972	-
8553	8390	8423	8525	-	8530	-
MOUNTRAIL COUNTY						
6780	12605	12630	12753	12854	12901	13421
6872	12280	12305	12428	12533	12584	13177
NELSON COUNTY						
1934	2513	2597	2721	-	-	2740
4664	2665	2735	2870	-	2882	2905
4785	2512	2596	2724	-	-	2745
OLIVER COUNTY						
8144	8405	8439	8556	-	8568	-
PEMBINA COUNTY						
700	1398	1434	1540	-	-	1560
PIERCE COUNTY						
435	4381	4423	4553	-	-	4585
706	4754	4800	4932	-	4970	4994
3920	5717	5758	5885	-	5940	-
5576	5550	5594	5727	-	5782	5850
RAMSEY COUNTY						
20	3035	3094	3213	-	3215	-
196	3500	3561	3686	-	3705	3740
407	3006	3076	3204	-	3226	3275
4745	2880	2945	3056	-	-	3080
4914	2772	2838	2958	-	-	2978
RENVILLE COUNTY						
6505	9358	9363	9476	-	9575	9839
6624	8917	8926	9038	-	9131	9308
6684	8928	8940	9049	-	9144	9268
7577	9746	9761	9869	9957	9982	10122
ROLETTE COUNTY						
316	4728	4770	4898	-	4920	4940

NDGS WELL NO.	ROUGHLK	ICEBX	UPPER BLK ISLAND	LOWER BLK ISLAND	DDWD	PC
SHERIDAN COUNTY						
665	6570	6608	6730	-	6750	-
684	6167	6198	6325	-	6344	-
693	6921	6958	7084	-	7110	-
735	6126	6157	6277	-	6303	-
SIOUX COUNTY						
631	5650	5702	5825	-	5835	-
SLOPE COUNTY						
8629	11616	11625	11733	-	11753	-
9244	11991	11999	12108	-	12132	-
STARK COUNTY						
6447	12487	12498	12610	-	12642	-
8088	12212	12224	12340	12383	12390	-
8169	11233	11249	11360	-	11384	12151
8342	12547	12554	12673	12709	12712	-
8665	11004	11022	11129	-	11152	-
9056	11644	11656	11770	-	11807	-
9135	11094	11118	11230	-	-	-
9256	11785	11791	11911	-	11944	-
9257	11644	11658	11773	-	11808	-
9322	12478	12485	12599	-	12630	-
9341	11953	11967	12084	-	-	-
9348	11544	11562	11674	-	11706	-
9407	11472	11487	11599	-	11630	-
9684	12365	12373	12481	-	12504	-
STUTSMAN COUNTY						
120	2642	2745	2850	-	2865	2917
134	3105	3186	3313	-	3333	3425
406	3014	3090	3221	-	3242	3318
644	3955	4021	4160	-	4177	4305
668	3370	3463	3587	-	3592	3695
669	3746	3818	3940	-	3960	4100
670	3498	3572	-	-	-	3700
671	3627	3698	3828	-	3834	3933
TOWNER COUNTY						
100	4313	4356	4480	-	-	4500
171	3606	3642	3763	-	-	3782
194	3569	3622	3744	-	-	3765
227	3818	3864	3997	-	-	4031
390	3871	3916	4041	-	-	4062
434	4246	4283	4409	-	-	4427
3980	4400	4441	4563	-	-	4584
WALSH COUNTY						
2623	2310	2374	-	-	-	-
2973	1608	1673	1787	-	-	1803

NDGS WELL NO.	ROUGHLK	ICEBX	UPPER BLK ISLAND	LOWER BLK ISLAND	DDWD	PC
WARD COUNTY						
47	8190	8207	8328	-	8400	-
105	10737	10738	10874	-	10980	-
588	9467	9485	9606	-	-	-
7612	11561	11583	11701	11803	11842	12220
WELLS COUNTY						
207	5611	5680	5805	-	5823	6020
609	4802	4872	5000	-	5022	5180
642	4776	4843	4974	-	5007	-
WILLIAMS COUNTY						
1231	13231	13251	13380	-	13587	13587
1385	13753	13775	13918	14087	14170	14800
1403	13262	13283	13427	13595	13669	-
1514	13513	13538	13683	13852	13928	14456
1636	13597	13617	13760	13919	14002	-
4321	13315	13336	13472	13640	13706	14284
4323	13165	13184	13317	13486	13538	-
4618	13279	13300	13423	13521	13532	-
4716	13319	13342	13489	13636	13710	-
5069	13483	13507	13653	13812	13905	-
5577	13150	13173	13304	-	-	-
5725	13305	13320	13464	-	-	-
5937	13292	13314	13450	-	-	-
6098	13957	13986	14134	14293	-	-
6478	13813	13838	13972	14094	14120	-
7931	14600	14625	14760	-	-	-
8316	12322	12342	12459	-	12560	-
8692	12827	12833	12973	-	-	-
9100	12593	12597	12727	-	-	-

APPENDIX C. Formation and Member Thicknesses

Thicknesses in feet; ROUGHLK = Roughlock Formation; ICEBX = Icebox Formation; UPPER BLK ISLAND = upper member of the Black Island Formation; LOWER BLK ISLAND = lower member of the Black Island Formation; DDWD = Deadwood Formation; and - = missing data.

NDGS WELL NO.	ROUGHLK	ICEBX	UPPER BLK ISLAND	LOWER BLK ISLAND	DDWD
ADAMS COUNTY					
6322	38	97	0	0	410
7642	23	94	0	0	-
BARNES COUNTY					
4640	86	135	15	0	17
BENSON COUNTY					
632	60	133	40	0	60
BILLINGS COUNTY					
291	8	116	29	5	-
3268	4	111	28	5	878
6228	15	132	50	27	906
6303	6	114	36	17	655
6913	12	120	43	15	-
7307	10	118	41	9	-
7520	6	122	42	8	-
7934	6	110	38	11	786
8226	9	116	51	0	-
8487	11	112	33	22	-
8603	2	114	36	9	-
BOTTINEAU COUNTY					
38	25	110	70	10	196
64	16	123	42	0	70
110	14	126	31	0	42
2219	20	118	52	0	120
4655	12	108	18	0	0
4790	20	112	76	0	-
4846	14	114	68	0	131
5184	22	112	52	0	55
BOWMAN COUNTY					
485	13	90	0	0	-
1575	13	94	-	0	-
BURKE COUNTY					
8893	14	114	95	31	242

NDGS WELL NO.	ROUGHLK	ICEBX	UPPER BLK ISLAND	LOWER BLK ISLAND	DDWD
BURLEIGH COUNTY					
19	50	127	20	0	262
151	41	124	10	0	353
174	52	123	21	0	262
701	48	128	20	0	-
723	61	129	15	0	-
756	67	140	17	0	-
763	46	123	24	0	-
765	46	123	24	0	-
772	45	126	23	0	-
1409	53	125	23	0	-
6264	55	127	21	0	208
7010	61	126	11	0	272
8674	48	126	20	0	255
CAVALIER COUNTY					
1694	39	115	22	0	0
2342	48	102	25	0	0
DICKEY COUNTY					
682	63	-	-	-	-
1394	60	120	0	0	87
DIVIDE COUNTY					
1546	11	125	-	-	-
2010	0	146	-	-	-
6798	0	131	107	14	442
7087	7	126	99	13	483
7660	0	127	-	-	-
7942	15	135	118	33	568
8498	8	121	-	-	-
8707	11	130	-	-	-
9677	0	131	92	6	-
DUNN COUNTY					
6086	18	125	52	75	-
6148	13	118	39	8	-
6530	10	120	40	10	-
7402	18	138	44	45	-
7412	5	140	-	-	-
7584	15	134	52	64	-
8077	17	141	65	-	-
8536	13	133	-	-	-
8536	13	133	-	-	-
8613	19	126	54	66	-
8709	20	135	68	51	-
8768	27	129	-	-	-
9027	20	129	43	62	-
9044	17	135	60	54	-

NDGS WELL NO.	ROUGHLK	ICEBX	UPPER BLK ISLAND	LOWER BLK ISLAND	DDWD
EDDY COUNTY					
437	68	133	27	0	95
768	60	139	22	0	-
EMMONS COUNTY					
16	72	122	8	0	288
23	57	137	3	0	-
43	55	128	9	0	311
7101	50	133	7	0	304
7146	79	127	15	0	277
7936	81	125	12	0	-
FOSTER COUNTY					
295	73	132	16	0	59
334	76	128	19	0	77
403	61	126	0	0	0
1105	168	127	4	0	-
1112	69	133	10	0	81
1126	63	-	-	-	-
1227	74	133	0	0	84
GOLDEN VALLEY COUNTY					
410	19	108	38	12	-
470	9	103	29	5	-
6272	0	101	17	0	413
6513	9	102	24	14	-
6563	9	98	33	0	-
7753	18	99	25	-	-
8590	4	133	65	0	-
9148	9	98	31	0	-
GRAND FORKS COUNTY					
580	94	157	-	-	0
1356	91	167	7	0	0
3191	94	120	11	0	0
3204	90	-	17	0	-
GRANT COUNTY					
5572	50	112	0	0	-
6420	48	118	0	0	-
6586	37	132	0	0	576
7020	21	120	11	0	-
8549	41	110	0	0	-
8680	49	111	0	0	534
HETTINGER COUNTY					
7075	31	106	3	0	557
7453	8	106	8	0	486
8312	19	103	19	0	-

NDGS WELL NO.	ROUGHLK	ICEBX	UPPER BLK ISLAND	LOWER BLK ISLAND	DDWD
LOGAN COUNTY					
590	85	125	7	0	-
1347	87	122	19	0	199
5523	76	127	5	0	-
MC HENRY COUNTY					
39	28	119	77	0	107
61	26	125	70	0	-
8307	35	118	55	0	-
8803	17	118	64	8	-
MC INTOSH COUNTY					
89	54	133	-	0	212
620	53	140	12	0	130
621	45	155	-	0	178
622	67	140	-	0	157
MC KENZIE COUNTY					
2373	30	145	157	104	896
6387	37	109	45	8	-
6414	37	105	68	10	-
7001	30	151	-	-	-
7203	30	123	-	-	-
7571	25	148	130	107	-
7631	30	118	56	62	-
7988	27	147	160	88	-
8090	27	152	154	109	-
8092	24	152	-	-	-
8131	36	130	67	82	-
8165	27	119	49	45	-
8187	37	110	49	37	-
8193	37	112	-	-	-
8268	27	116	-	-	-
8302	35	114	-	-	-
8314	40	111	42	30	860
8626	29	135	-	-	-
9004	35	-	-	-	-
MCLEAN COUNTY					
22	30	115	35	0	-
49	22	118	60	25	-
7783	23	130	115	53	662
8060	21	128	103	47	-
8711	30	115	43	0	270
8720	33	118	47	0	303
8993	42	119	50	33	-
MERCER COUNTY					
21	13	130	68	0	-
8675	16	123	42	21	-
8712	21	126	53	56	-

NDGS WELL NO.	ROUGHLK	ICEBX	UPPER BLK ISLAND	LOWER BLK ISLAND	DDWD
MORTON COUNTY					
26	66	128	0	0	442
1620	14	130	21	0	-
3859	59	122	0	0	451
7340	11	133	38	0	-
7691	40	114	11	0	-
7797	25	127	0	0	-
7937	16	116	0	0	-
8158	44	120	14	0	357
8553	33	102	5	0	-
MOUNTRAIL COUNTY					
6780	25	123	101	47	520
6872	25	123	105	51	593
NELSON COUNTY					
1934	84	124	19	0	0
4664	70	135	12	0	23
4785	84	128	21	0	0
OLIVER COUNTY					
8144	34	117	12	0	-
PEMBINA COUNTY					
700	36	106	20	0	0
PIERCE COUNTY					
435	42	130	32	0	0
706	46	132	38	0	24
3920	41	127	55	0	-
5576	44	133	55	0	68
RAMSEY COUNTY					
20	59	119	2	0	0
196	61	125	19	0	35
407	70	128	22	0	49
4745	65	111	24	0	0
4914	66	120	29	0	0
RENVILLE COUNTY					
6505	5	113	99	0	264
6624	9	112	93	0	177
6684	12	109	95	0	124
7577	15	108	88	25	140
ROLETTE COUNTY					
316	42	128	22	0	20

NDGS WELL NO.	ROUGHLK	ICEBX	UPPER BLK ISLAND	LOWER BLK ISLAND	DDWD
SHERIDAN COUNTY					
665	38	122	20	0	-
684	31	127	19	0	-
693	37	126	26	0	-
735	31	120	26	0	-
SIOUX COUNTY					
631	52	123	10	0	-
SLOPE COUNTY					
8629	9	108	20	0	-
9244	8	109	24	0	-
STARK COUNTY					
6447	11	112	32	0	-
8088	12	116	43	7	-
8169	16	111	24	0	767
8342	7	119	36	3	-
8665	18	107	23	0	-
9056	12	114	37	0	-
9135	24	112	-	-	-
9256	6	120	33	0	-
9257	14	115	35	0	-
9322	7	114	31	0	-
9341	14	117	-	-	-
9348	18	112	32	0	-
9407	15	112	31	0	-
9684	8	108	23	0	-
STUTSMAN COUNTY					
120	103	105	15	0	52
134	81	127	20	0	92
406	76	131	21	0	76
644	66	139	17	0	128
668	93	124	5	0	103
669	72	122	20	0	140
670	74	128	0	0	0
671	71	130	6	0	99
TOWNER COUNTY					
100	43	124	20	0	0
171	36	121	19	0	0
194	53	122	21	0	0
227	46	133	34	0	0
390	45	125	21	0	0
434	37	126	18	0	0
3980	41	122	21	0	0
WALSH COUNTY					
2623	64	-	-	-	-
2973	65	114	16	0	0

NDGS WELL NO.	ROUGHLK	ICEBX	UPPER BLK ISLAND	LOWER BLK ISLAND	DDWD
WARD COUNTY					
47	17	121	72	0	-
105	1	136	106	0	-
588	18	121	-	-	-
7612	22	118	102	39	378
WELLS COUNTY					
207	69	125	18	0	197
609	70	128	22	0	158
642	67	131	33	0	-
WILLIAMS COUNTY					
1231	20	129	-	-	0
1385	22	143	169	83	630
1403	21	144	168	74	-
1514	25	145	169	76	528
1636	20	143	159	83	-
4321	21	136	168	66	578
4323	19	133	169	52	-
4618	21	123	98	11	-
4716	23	147	147	74	-
5069	24	146	159	93	-
5577	23	131	-	-	-
5725	15	144	-	-	-
5937	22	136	-	-	-
6098	29	148	159	-	-
6478	25	134	122	26	-
7931	25	135	-	-	-
8316	20	117	101	0	-
8692	6	140	-	-	-
9100	4	130	-	-	-

APPENDIX D. Core Descriptions of Strata From Formations of the Winnipeg Group

Wells are arranged by NDGS Well Number; depths are from the Kelly Bushing as given on the core boxes; operator names and well names are original names; T. S. = thin section description; sandstone classification is after Williams and others (1954); shale classification is after Potter and others (1980); limestone classification is after Folk (1959).

NDGS Well No. 20
Union Oil Company - Aanstad No. 1
CSE, Sec. 29, T. 158 N., R. 62 W.
Ramsey County

Depth (ft.)	Description
3059-3102	Limestone, nodular, argillaceous, biomicrite, medium gray matrix with light gray nodules, fossils include echinoderm, brachiopod, and unidentified fragments, numerous microstylolites in matrix.
T. S. 3069	Limestone, biomicrite, light gray nodules in brownish gray matrix, matrix slightly dolomitized, stylolites in matrix, fossils include echinoderm, brachiopod,trilobite, and other, unidentified fossil fragments.
T. S. 3082	As above.
3102-3106	Limestone, medium gray to light gray, argillaceous, 3 inch beds of light gray limestone in medium gray matrix, slightly dolomitized, moderately fossiliferous, fossils include brachiopod, echinoderm, and unidentified fossil fragments, slightly pyritized, grades to shale at base.
3106-3112	Clayshale, greenish gray, noncalcareous, disaggregated.

NDGS Well No. 207
Continental Oil Co. - Lueth No. 1
SESE, Sec. 27, T. 146 N., R. 73 W.
Wells County

Depth (ft.)	Description
5750-5754	Clayshale, dark greenish gray, platy parting, noncalcareous, small (2 mm) inclusions, unidentified fossil fragments.
5754-5757	Clayshale, dark greenish gray, structureless, platy to flaggy partings.
5757-5774	Clayshale, greenish gray to dusky yellowish green, worm burrows common, occasional brachiopods, slickensides.
5774-5777.5	No core.
5777.5-5789	Clayshale, dark greenish gray, bioturbated, platy partings.
5789-5793	Clayshale, dusky yellowish green, structureless, unidentified fossil fragments.
5793-5804	Clayshale, medium bluish gray, bioturbated, platy partings.
5804-5807	Clayshale, medium bluish gray, lenses of well-rounded, medium- to coarse-grained sandstone randomly oriented within shale.
5807-5810	Clayshale, medium bluish gray, structureless, platy partings.
5810-5811.5	Clayshale, lenticular sandstone inclusions, fine- to coarse-grained sandstone grains, well-rounded, reduced sand upward, sand grains "floating" in shale.

Depth (ft.)	Description
T. S. 5811	Sandstone, quartz wacke, well-rounded to rounded, fine- to medium-grained, low porosity, clay matrix, lesser quartz cement, pyritized.
5811-5814	Sandstone, quartz arenite, medium gray, fine to medium grained, well-rounded, well indurated, alternating quartz cement and pyrite cement.
5814-5815	Sandstone, quartz wacke, light gray, fine-grained, well-rounded, bioturbated, clay matrix.
5815-5818	Sandstone, quartz arenite, light gray, fine-to coarse-grained, well-rounded, very friable, clay matrix, quartz and hematite cement.

NDGS Well No. 1385
Amerada Petroleum Corp. - N. D. "A" No. 9
SESW, Sec. 16, T. 156 N., R. 95 W.
Williams County

Depth (ft.)	Description
14129-14134.5	Interlaminated sandstone and siltstone, light greenish gray to dark greenish gray, fine- to medium-grained, rounded, poorly-sorted sandstones, soft sediment deformation.
T. S. 14129	Sandstone, quartz wacke, fine- to coarse-grained, poorly-sorted, well-rounded, clay matrix and minor calcite cement, low porosity.
T. S. 14129.5	Clayshale, sandy, fine- to coarse-grained, well-rounded, quartz grains "floating" in clay matrix.
T. S. 14132.5	Sandstone, quartz arenite, fine-to medium-grained, well-rounded to rounded, quartz cement, minor hematite cement and clay matrix.

Depth (ft.)	Description
T. S. 14133	Sandstone, quartz wacke, very fine- to coarse-grained, poorly-sorted, well-rounded, clay matrix, quartz cement, minor hematite cement.
14134.5-14138	Sandstone, quartz arenite, dark reddish brown, fine- to medium-grained, well-rounded, pervasive hematite cement, 1-2 mm stringers of sandy shale.
T. S. 14136	Sandstone, quartz arenite, fine- to medium-grained, well rounded, poorly sorted, hematitie and quartz cement, minor clay matrix, high porosity.
14138-14146	Sandstone, quartz wacke, greenish gray to very light gray, fine- to coarse-grained, well-rounded, poorly sorted, lenses of green shale, alternating quartz cement and clay matrix.
T. S. 14141	Sandstone, quartz wacke, fine- to medium-grained, rounded, poorly sorted, clay matrix, calcite cement, finely laminated.
T. S. 14144	Sandstone, quartz arenite, fine- to medium-grained, well-rounded, quartz cement, minor clay rimming quartz grains, moderate porosity.
14146-14149.5	Interlaminated sandstone and clayshale, light gray and dusky red, fine- to coarse-grained, shale lenses within sandstone, quartz cement and clay matrix.
T. S. 14146	Sandstone, quartz arenite, fine- to coarse-grained, well-rounded, poorly sorted, quartz cement, minor clay matrix, high porosity.
T. S. 14147	Sandstone, quartz arenite, medium-grained, well-sorted, well-rounded, quartz cement, moderate porosity.

Depth (ft.)	Description
14149.5-14152.3	Sandstone, silty, quartz wacke, dark reddish brown, fine- to medium-grained, rounded, alternating friable and well indurated, occasional thin layers of siltstone and clayshale.
14152.3-14155.2	Sandstone, quartz arenite, grayish pink, medium-grained, well-rounded, well-sorted, quartz cement, trace hematite cement, mostly structureless.
T. S. 14154.5	Sandstone, quartz arenite, medium-grained, well-sorted, well-rounded, quartz cement, trace hematite rimming grains.
14155.2-14163.6	Clayshale, alternating reddish brown and dark greenish gray, occasional soft sediment deformation, mud cracks, occasional horizontal laminations.
T. S. 14163	Clayshale, 5 mm laminations of clayshale with occasional laminations of siltstone and fine-grained sandstone.
14163.6-14165.4	Clayshale, grayish black, fissile partings.
14165.4-14170	Quartz arenite, very light gray, medium-grained, well-sorted, rounded, quartz cement, conodonts.

NDGS Well No. 2010
Carter Oil Co. - Moore No. 1
NWNE, Sec. 7, T. 163 N., R. 102 W.
Divide County

Depth (ft.)	Description
10863-10868	Interlaminated siltstone and clayshale, medium gray, numerous phosphate nodules.
10868-10877	Clayshale, dark greenish black, platy partings, occasional worm burrows.

Depth (ft.)	Description
10877-10881	Clayshale, silty, medium dark gray, flaggy partings.
10881-10885	No core.
10885-10885.5	Clayshale, dark gray, structureless, platy partings.
10885.5-10891	Sandstone, quartz wacke, medium light gray, bioturbated, clay matrix, friable, contains 3 cm lenses of quartz arenitic sandstone.
10891-10891.5	Clayshale, silty, dark gray, structureless.
10891.5-10893	Sandstone, quartz wacke, medium to light gray, very fine-to fine-grained, well-sorted, bioturbated, clay matrix.
10893-10894	Sandstone, quartz wacke, medium gray, fine-grained, well-sorted, clay matrix, rip-up clasts.
T. S. 10893	Sandstone, quartz wacke, fine-grained, well-sorted, rounded, clay matrix, low porosity, rounded sandstone, rip-up clasts.
10894-10899	Clayshale, dark gray, platy parting, siderite lining fractures.
10899-10900.5	Siltstone, medium light gray, zones of poorly sorted sandstone, clay matrix.
T. S. 10900	Siltstone, occasional medium-grained, subangular, poorly sorted quartz grains, clay matrix, low porosity.
10900.5-10902	Sandstone, quartz wacke, medium gray, clay matrix, bioturbated.

Depth (ft.)	Description
10902-10905.5	Sandstone, quartz arenite, very light gray, fine-grained, well-sorted well indurated, occasional horizontal laminae, stylolites.
T. S. 10903	Sandstone, quartz arenite, fine-grained, well-sorted, quartz overgrowths and calcite cement.
10905.5-10920	Sandstone, quartz wacke, medium dark gray, fine- to medium-grained.
T. S. 10906	Sandstone, quartz wacke, fine- to medium-grained, rounded, clay matrix, clay filled stylolites.
T. S. 10909	Sandstone, quartz arenite, medium-grained, rounded, quartz and anhydrite cement, minor clay matrix.
10920-10924	Sandstone, quartz arenite, very light gray, fine-grained, rounded, well-sorted, horizontal and cross laminated, quartz cement, stylolites.
10924-10925.5	Sandstone, quartz wacke, light gray, fine-grained, rounded, well-sorted, bioturbated, clay matrix and quartz cement.
10925.5-10927.5	Sandstone, quartz arenite, light gray, very fine- to fine-grained, rounded, quartz cement.
T. S. 10927	Sandstone, quartz arenite, fine-grained, well-sorted, quartz cemented, low porosity.
10927.5-10928.5	Siltstone, medium gray, silt and clay sized particles, bioturbated, possible water escape structures.
10928.5-10935	Sandstone, quartz wacke, medium light gray, fine-grained, rounded, well-sorted, bioturbated with some worm burrows, friable, clay matrix, increased silt content downward.

Depth (ft.)	Description
10935-10940	Sandstone, quartz arenite, light gray, fine-grained, rounded, bioturbated, occasional worm burrows, friable, occasional thin shaly layers, bioturbation increases downward.
T. S. 10936	Sandstone, quartz arenite, very fine- to medium-grained. rounded to subrounded, poorly sorted, quartz overgrowths, excellent porosity.
T. S. 10938	Sandstone, quartz wacke, poorly sorted, medium- to fine-grained, rounded, clay matrix, low porosity.

NDGS Well No. 2373
Amerada Petroleum Corp., Antelope Unit "A" No. 1
NESE, Sec. 1, T. 152 N., R. 95 W.
McKenzie County

Depth (ft.)	Description
14057-14050.8	Sandstone, quartz arenite, light gray, fine-grained, well-sorted, heavily bioturbated, vertical worm burrows, gastropod (?) fragment.
T. S. 14057	Sandstone, quartz arenite, fine-grained, well-sorted, rounded, intercalated lenses of quartz cementation and clay matrix, quartz overgrowths inhibited in zones with clay matrix.
T. S. 14059	Sandstone, quartz wacke, fine-grained, well-sorted, rounded, clay matrix, low porosity.
14060.8-14066.8	Sandstone, quartz arenite, medium light gray, medium- to fine-grained, rounded to subrounded, quartz cement, occasional worm burrows, stylolites spaced at approximately 15 cm intervals.
14066.8-14076	Sandstone, quartz arenite, medium light gray, medium- to fine-grained, moderately- to well-sorted, quartz cement, mostly structureless, slight oil stain.

Depth (ft.)	Description
T. S. 14075	Sandstone, quartz arenite, fine- to medium-grained, well-sorted, quartz cemented, dark inorganics along stylolites, structureless, low porosity.
14075-14107	Sandstone, quartz arenite, very light gray, medium- to fine-grained, well-sorted, well-rounded, phosphate nodules.
T. S. 14084	Sandstone, quartz arenite, fine- to medium-grained, well-sorted, quartz cement, inorganics along stylolites, isolated zones of clay matrix.
T. S. 14095	Sandstone, quartz arenite, medium-grained, well-sorted, well-rounded, quartz cemented, low porosity.
T. S. 14103	As above.
14107-14108	Clayshale, grayish black, bioturbated.
14108-14111	Sandstone, quartz arenite, very fine- to fine-grained, quartz cement, horizontal and vertical worm burrows.
14111-14112.5	Siltstone, sandy, dark gray, clay matrix, sandstone lenses.
14112.5-14116.5	Sandstone, quartz arenite, fine- to medium-grained, well-rounded, well-sorted, calcite cement, bioturbation.
T. S. 14112.7	Sandstone, quartz arenite, medium-grained, well-sorted, well-rounded, matrix supported calcite cement, clay matrix along occasional wispy seams.
14116.5-14120	Sandstone, quartz wacke, dark gray, fine-grained, rounded, bioturbated, clay matrix and quartz cement, possible soft sediment deformation, occasional lenses of black shale.

Depth (ft.)	Description
14120-14122.5	Sandstone, quartz wacke, greenish gray, fine-grained, well-sorted, worm burrows and bioturbated, friable, black phosphate nodules, sharp contact with underlying and overlying rock.
14122.5-14123.2	Clayshale, silty, dark greenish gray, fissile partings.
14123.2-14128	Sandstone, quartz wacke, light greenish gray to very light gray, fine- to medium-grained, well-rounded, poorly sorted, clay matrix, bioturbated, water escape structures.
T. S. 14125	Sandstone, quartz wacke, very fine- to medium-grained, poorly sorted, well-rounded, occasional siltstone and shale rock fragments, clay matrix, very low porosity.
14125-14146	No core.
14146-14152	Clayshale, dusky red and dark grayish green, fissile partings.
14152-14154.5	Intercalated sandstone and shale, dark gray shale and light gray sandstone, medium-grained, soft sediment deformation, possible ripple marks.
14154.5-14161	Sandstone, quartz arenite, dark reddish brown, fine- to medium-grained, occasional cross laminations, hematite and quartz cement, lesser amounts of clay matrix.
T. S. 14155	Interlaminated sandtone and clayshale, sandstone medium- to fine-grained, poorly-sorted, clay matrix, soft sediment deformation.
T. S. 14158	Sandstone, quartz arenite, fine- to coarse-grained, well-rounded poorly-sorted, quartz cement, trace amounts of hematite cement, occasional pockets of clay matrix, low porosity.

Depth (ft.)	Description
14193-14198	Clayshale, dark reddish brown, sandstone lenses and occasional sandstone laminations, sandstone fine- to medium-grained, clay matrix.
T. S. 14194	Clayshale, occasional lenses of siltstone or fine-grained sandstone.
T. S. 14196	Sandstone, quartz arenite, fine- to medium-grained, well-rounded to rounded, quartz and hematite cement, minor amounts of calcite cement, moderate porosity.
14198-14200	Sandstone, quartz arenite, dark reddish brown, fine- to medium-grained, mostly structureless, quartz cement, occasional cross laminations.
T. S. 14199	Sandstone, quartz arenite, very fine- to fine-grained, well-sorted, trace amounts of glauconite, quartz cement, minor clay matrix, very low porosity.
14200-14201	Clayshale, intercalated dark reddish brown and dark greenish gray, commonly poorly sorted, sandstone lenses.
T. S. 14200	Clayshale, interlaminated with siltstone and sandstone lenses, sandstone fine- to medium-grained, poorly sorted, occasional glauconite grains.
14201-14209	Sandstone, quartz arenite, dark reddish brown, medium- to fine-grained, subrounded, well-sorted, quartz and hematite cement, commonly cross laminated.
T. S. 14207	Sandstone, quartz arenite, fine-grained, well-sorted, glauconite, detrital clay grains, trace tourmaline and rutile, quartz cement, hematite cement rimming quartz grains, minor clay matrix.
T. S. 14208	As above

Depth (ft.)	Description
14209-14253	No core.
14253-14257	Sandstone, quartz arenite, light gray, fine-grained, well-sorted rounded, low angle cross laminations, quartz cement.
T. S. 14256	Sandstone, quartz arenite, fine-grained, well-sorted, well-rounded, quartz cement, minor calcite cement, very low porosity.

NDGS Well No. 3268
Amerada Petroleum Corp. - Scoria Unit No. 8
SESW, Sec. 10, T. 139 N., R. 101 W.
Billings County

Depth (ft.)	Description
12605-12616	Sandstone, light greenish gray, very fine- to medium-grained, rounded to well-rounded, clay matrix, very friable, fine layers of light green clayshale.
T. S. 12616	Sandstone, quartz wacke, fine-grained, well-sorted, rounded,
12616-12618	Clayshale, dark greenish gray, sandy, shale intercalated with argillaceous sandstone, sandstone increased downward, occasional black nodules.
T. S. 12616	Interlaminated clayshale and argillaceous sandstone, quartz grains, fine- to medium-grained, rounded to well-rounded, very low porosity.
12618-12623	Sandstone, quartz arenite, very light gray, fine-to medium-grained, rounded, well-sorted, structureless, quartz cement, minor clay matrix, occasional stylolites.
T. S. 12622	Sandstone, quartz arenite, medium-grained, well-sorted, quartz cement, low porosity.

Depth (ft.)	Description
12623-12624.4	Sandstone, quartz wacke, greenish gray, fine- to very fine-grained, well-sorted, rounded, clay matrix.
T. S. 12624.2	Sandstone, quartz wacke, fine-grained, well-sorted, rounded to well-rounded, trace feldspar and glauconite, clay matrix, very low porosity.
12624.4-12627	Interlaminated sandstone and clayshale, dark greenish gray to dark reddish brown, quartz grains fine- to medium-grained, clay matrix, soft sediment deformation.
T. S. 12625	Interlaminated sandstone and shale, shales show disturbed bedding, possible soft sediment deformation, quartz grains fine- to medium-grained, well-rounded to subrounded, clay matrix and calcite cement.
12627-12628	Sandstone, quartz arenite, dusky red, fine- to coarse-grained, well-rounded to rounded, occasional laminae, few clasts of green clay, hematite cement.
T. S. 12627.5	Sandstone, quartz arenite, medium-grained, well-sorted, well-rounded, hematite cement, quartz cement, lesser amonts of calcite and anhydrite cement, low porosity.
12628-12631	Sandstone, light gray to medium light gray, quartz wacke, fine- to medium-grained, clay matrix, numerous stylolites, soft sediment deformation.
T. S. 12629	Sandstone, quartz wacke, fine-grained, well-sorted, subrounded, clay matrix, hematite cement, moderate porosity.
	Deadwood Formation
12631-12633	Limestone, micrite, olive gray, trilobite fragments and other unidentified fossil fragments, occasional stylolites.

NDGS Well No. 6148
Amoco Oil Co. - Heiser No. 1
SWSW, Sec. 2, T. 141 N., R. 96 W.
Dunn County

Depth (ft.)	Description
13408-13419.5	Sandstone, quartz wacke, brownish to yellowish gray, fine- to medium-grained, rounded to well-rounded, moderate to heavy bioturbation, stylolites, clay matrix.
T. S. 13413	Sandstone, quartz wacke, fine- to medium-grained, well-rounded to rounded, poorly sorted, clay matrix, minor calcite cement.
13419.5-13420.5	Clayshale, silty, dark gray, sharp contact with overlying sandstone, grades downward to shaly sandstone.
13420.5-13421	Sandstone, quartz wacke, medium light gray, medium-grained, well-sorted, bioturbated.
13421-13424	Clayshale, silty, dark gray, lenses of siltstone and sandstone.
T. S. 13421.5	Siltstone, subangular to subrounded grains, clay matrix, horizontal stratification, sharp contact with underlying sandstone.
13424-13434.5	Sandstone, quartz wacke, light greenish gray, medium- to fine-grained, well-rounded to rounded, clay matrix, friable.
T. S. 13429.8	Sandstone, quartz wacke, fine- to medium-grained, poorly sorted, rounded to well-rounded, clay matrix, minor quartz cement, high porosity.
13434.5-13436	Sandstone, quartz arenite, very light gray, very fine-grained, well-sorted, rounded to well-rounded, structureless, well indurated, quartz cement.

Depth (ft.)	Description
13436-13439	No core.
13439-13442	Sandstone, quartz arenite, very light gray, very fine-grained, rounded to well-rounded, well-sorted, quartz cement and occasional bioturbation, few stylolites.
T. S. 13441	Sandstone, quartz arenite, fine- to medium-grained, subrounded, quartz cemented zone separated from clay matrix layer by stylolite.
13442-13448	Sandstone, interlaminated quartz arenite and quartz wacke, light and dark gray to greenish gray, fine-grained, rounded, well-sorted, alternating 5 cm laminations of quartz arenite and quartz wacke, quartz wacke slightly friable.
13448-13449	Clayshale, sandy, dark gray, fine-grained sand grains "floating" in shale matrix.
13449-13451	Sandstone, quartz arenite, very light gray, fine- to medium-grained, rounded, well-sorted, structureless, few stylolites.
T. S. 13450	Sandstone, quartz arenite, fine- to medium-grained, well-rounded to subrounded, quartz cement, and clay matrix.
13451-13453	Sandstone, quartz wacke, light gray, fine- to medium-grained, clay matrix and quartz cement, bioturbated.
13453-13453.6	Clayshale, medium dark gray, sandy, lenticular sand lenses, sharp contact with underlying sandstone.
	Deadwood Formation
13453.6-13455	Sandstone, quartz arenite, fine- to medium-grained, well-rounded, calcite cemented, structureless.

Depth (ft.)	Description
T. S. 13453.7	Sandstone, quartz arenite, fine- to medium-grained, well-rounded to rounded, matrix supported calcite cement, low porosity.
13455-13456.3	Clayshale, sandy, medium gray, fine sand grains floating in shale matrix.
13456.3-13457	Sandstone, quartz arenite, medium dark gray, fine-grained, rounded, slight bioturbation, calcite cement, calcite replaced worm burrow.
T. S. 13456.5	Sandstone, quartz arenite, fine- to medium-grained, well-rounded to rounded, matrix supported calcite cement, calcite filled vug, thin layers of clay matrix.

NDGS Well No. 6228
Gulf Oil Company - Zabolotny No. 1-3-4-A
SWNW, Sec. 3, R. 144 N., R. 98 W.
Billings County

Depth (ft.)	Description
14295-14303	Sandstone, quartz arenite, light gray, fine- to medium-grained, rounded, quartz cement and clay matrix, bioturbated, occasional stylolites.
14303-14304	Siltstone, dark gray, sandy, water escape structures.
14304-14313.4	Sandstone, quartz wacke, light greenish gray, fine- to medium-grained, rounded to well-rounded, occasional thin shale lenses, small amount of bioturbation, clay matrix, minor quartz cement.
14313.4-14317	Sandstone, quartz wacke, medium light gray to very light gray, fine-grained, well-sorted, structureless, quartz cement.
14317-14319	No core.

Depth (ft.)	Description
14319-14332.3	Quartz arenite, medium dark gray to light gray, fine-grained, well-sorted, quartz cement, mostly structureless, isolated zones of bioturbation.
14332.3-14341.2	Interbedded sandstone and shale, medium light gray, quartz cement, bioturbated, well-sorted, fine-grained, quartz arenite interbedded with dark gray silty shale.

Deadwood

14341.2-14345	Sandstone, quartz arenite, medium light gray, very fine- to fine-grained, well-rounded, possible trilobite fragment.

NDGS Well No. 7020
Texas Pacific - Steckler No. 1
SENE, Sec. 5, T. 137 N., R. 88 W.
Grant County

Depth (ft.)	Description
10280-10305	Clayshale, grayish black to dark gray, fissile parting, slickensides, silty toward the lower part, fossils include trilobite and brachiopod fragments, worm burrows.
10305-10307	Clayshale, silty, dark gray, sandstone infilled worm burrows, rounded quartz grains floating in shale, nodules of sandstone near lower contact.
T. S. 10306.2	Sandstone, quartz wacke, fine-grained, well-sorted, rounded to subrounded, clay matrix and calcite cement, trace pyrite, high porosity.
T. S. 10306.8	Interlaminated sandstone and clayshale, sandstone contains very fine to fine quartz grains, subrounded to rounded, clay matrix.

Depth (ft.)	Description
10307-10307.8	Sandstone, quartz wacke, light gray, fine-grained, well-sorted, rounded, heavily bioturbated, medium-grained sandstone within worm burrows, calcite cement and clay matrix.
10307.8-10308.4	Clayshale, dark gray, distorted laminae, sandstone filled ball and pillow structures.
10308.4-1031203	Sandstone, quartz arenite, very light gray, fine-grained, well-sorted, rounded to well-rounded, interbedded bioturbated and structureless zones, calcite and quartz cement.
T. S. 10308.6	Sandstone, quartz arenite, very fine- to medium-grained, well-rounded to subrounded, wispy interlaminae of shale, calcite cement, low porosity.
10312.3-10315.5	Interlaminated sandstone and clayshale, dark gray, sandstone contains fine-grained quartz grains with clay cement, occasional quartz grains floating in shale.
10312-10315.5	Sandstone, quartz wacke, fine-grained, well-sorted, rounded to subrounded, clay matrix, high porosity.
	Deadwood Formation
10315.5-10316.5	Sandstone, quartz arenite, light gray, fine- to medium-grained, rounded to well-rounded, bioturbated.

NDGS Well No. 7146
Chevron U. S. A., Inc. - Naaden No. 1
NWNE, Sec 15, R. 136 N., R. 75 W.
Emmons Co.

Depth (ft.)	Description
5260-5274	Clayshale, dark greenish gray, platy partings, occasional worm burrows, numerous brachiopods including orthids, other unidentified fossils, occasional pyritization, phosphate grains.
T. S. 5269.5	Clayshale, few siltstone grains, brachiopod fossil fragment.
5274-5276	Clayshale, medium bluish gray, orthid brachiopods and unidentified fossil fragments, some pyritization of fossil fragments.
5276-5283	Clayshale, dark greenish gray, platy partings, slight bioturbation, unidentified fossil fragments.
5283-5288	Clayshale, dark greenish gray, platy partings, slickensides, pyritic.
5288-5292	Clayshale, mottled bluish gray and olive gray, platy partings, structureless.
5292-5298.5	Clayshale, dark greenish gray, slickensides, structureless.
5298.5-5300	Sandstone, quartz wacke, medium gray, medium- to fine-grained, well-rounded, clay matrix.
T. S. 5299	Sandstone, quartz wacke, medium-grained, rounded, clay cement, low porosity.
5300-5303	Clayshale, dark greenish gray, platy partings occasional 3 mm lenses of medium-grained clay cemented sandstone.

Depth (ft.)	Description
5303-5303.7	Sandstone, quartz wacke, medium gray, fine- to medium-grained, clay matrix with pyrite and calcite cement.
5303.7-5307	Interlaminated clayshale and sandstone, dark greenish gray, sandstone either lensoid or in thin laminations, shale increases upward.
T. S. 5304	Sandstone, quartz arenite, medium-grained, poorly-sorted, well-rounded to rounded, interlaminated with silty and sandy shale.

Deadwood Formation

Depth (ft.)	Description
5307-5309	Limestone, micritic, slightly dolomitic, occasional quartz and feldspar grains, trace glauconite, pyritic.

NDGS Well No. 7577
Shell Oil Co. - Dewing No. 12-15
swnw, Sec. 15, R. 150 N., R. 86 W.
Renville County

Depth (ft.)	Description
9875-9876	Clayshale, sandy, medium dark gray, sand grains fine-grained and rounded, decreasing sand upward.
9876-9877.5	Sandstone, quartz wacke, fine- to medium-grained, rounded, clay matrix, well indurated, bioturbated, wispy stringers of gray shale.
9877.5-9890.5	Sandstone, quartz arenite, very light gray, very fine- to coarse-grained, rounded, poorly sorted, quartz cement, well indurated, mostly structureless, occasional stylolites.
T. S. 9881	Sandstone, quartz arenite, fine- to medium-grained, poorly sorted, rounded to well-rounded, quartz cement, minor anhydrite cement, high porosity.

Depth (ft.)	Description
T. S. 9890.3	Sandstone, quartz arenite, fine- to coarse-grained, poorly sorted, quartz cement, trace anhydrite cement, low porosity.
9890.5-9901.3	Sandstone, quartz wacke, mottled medium gray and pale olive, fine- to medium-grained, well-rounded, clay matrix, bioturbated, occasional microstylolites.
9911.3-9902.5	Sandstone, quartz wacke, mottled very light gray and light grayish green, rounded to well-rounded, clay matrix.
T. S. 9901.6	Sandstone, quartz wacke, fine- to medium-grained, well-rounded, clay matrix, minor quartz cement, high porosity.
9901.3-9911	Sandstone, quartz wacke, mottled very light gray and medium gray, fine- to coarse-grained, poorly sorted, well-rounded, bioturbated, occasional worm burrows, clay matrix.
9911-9915.8	Sandstone, quartz arenite, light gray, medium-grained, rounded, quartz cement, mostly structureless, isolated stylolites.
T. S. 9911.5	Sandstone, quartz arenite, fine- to medium-grained, well-rounded, quartz cement, minor clay matrix, moderate porosity.
9915.8-9919.3	Sandstone, quartz wacke, mottled light gray, dark gray, and grayish orange, fine- to medium-grained, rounded, bioturbated, few worm burrows.
9919.3-9927	Sandstone, quartz arenite, light gray, fine- to medium-grained, rounded, well-sorted, quartz cement, occasional phosphate nodules, mostly structureless.
T. S. 9921	Sandstone, quartz arenite, medium-grained, well-sorted, well-rounded, oval-shaped calcite filled worm burrow, quartz cement, trace anhydrite cement, low porosity.

Depth (ft.)	Description
9927-9928	Sandstone, quartz wacke, greenish gray, fine- to medium-grained, rounded, clay matrix, very friable, most of sample disaggregated in core box.
T. S. 9927.5	Sandstone, quartz wacke, fine- to medium-grained, poorly sorted, well-rounded, clay matrix, high porosity.
9928-9933	Sandstone, quartz wacke, mottled light gray and yellow brown, fine- to medium-grained, rounded to well-rounded, poorly sorted, clay matrix, bioturbated, occasional worm burrows.
9933-9934	Sandstone, quartz arenite, light gray, fine- to medium-grained, rounded, quartz cement, stylolite.
T. S. 9933.5	Sandstone, quartz arenite, fine- to medium-grained, well-rounded, quartz cement, high porosity.

NDGS Well No. 8169
Gulf Oil Co. - Leviathan 1-21-18
NENW, Sec. 21, T. 138 N., R. 92 W.
Stark County

Depth (ft.)	Description
11336-11338	Clayshale, olive gray, occasional slickensides, pyritic.
11338-11339.5	Intercalated clayshale and siltstone, olive gray, pyritic, nodules of siltstone within shale.
11339.5-11342	Sandstone, quartz wacke, grayish black, medium-grained, clay matrix, some pyrite.
T. S. 11340	Clayshale, sandy, medium-grained, well rounded quartz grains in clay matrix.
11342-11343.5	Sandstone, quartz wacke, dark gray, medium- and fine-grained quartz grains "floating" in clayshale.

Depth (ft.)	Description
11343.5-11345.5	Sandstone, quartz wacke mottled dark gray and very light gray, medium-grained, rounded, bioturbated.
T. S. 11344	Sandstone, quartz wacke, fine-grained, well-sorted, rounded to subrounded, occasional zones of shale, clay matrix, high porosity.
T. S. 11345	Sandstone, quartz wacke, fine- to medium-grained, poorly-sorted, well-rounded, detrital glauconite grains, clay matrix, minor calcite cement, moderate porosity.
11345.5-11347	Sandstone, greenish gray, fine-grained, rounded, alternating clay matrix and calcite cement.
11347-11356	Sandstone, quartz wacke, dark greenish gray, very fine- to fine-grained, rounded grains, bioturbated in places, clay matrix, occasionally pyritic.
T. S. 11449	Sandstone, quartz wacke, very fine- to fine-grained, well-sorted, subrounded, clay matrix, glauconite grains, small lenses of clayshale.
11356-11357	Sandstone, quartz arenite, medium light gray, rounded, well indurated, structureless, quartz cemented.
T. S. 11356	Sandstone, quartz arenite, medium-grained, well-sorted, subrounded, extensive quartz cementation, very low porosity.
11357-11363	Sandstone, quartz wacke, greenish gray, fine- to medium-grained, well-rounded to rounded, occasional lenses of green clayshale, bioturbated in places, some disturbed horizontal laminations.
T. S. 11359	Interlaminated sandstone, siltstone, and shale, sandstones contain fine- to coarse-grained, well-rounded calcite cemented, quartz grains.

Depth (ft.)	Description
T. S. 11362	Sandstone, quartz wacke, fine- to medium-grained, well-sorted, well-rounded, clay matrix, high porosity.
11363-11363.5	Clayshale, olive black, fissile, waxy.
11363.5-11364	Sandstone, light green to gray green, well-rounded to rounded, structureless quartz arenite interlaminated with quartz wacke, load structures at contacts between the quartz wacke and quartz arenite.
11364-11365.5	Clayshale, dark gray fissile, few quartz grains, isolated pyrite crystals.
11365.5-11366.5	Interlaminated sandstone and clayshale, bioturbated, fine- to medium-grained sandstone, dark gray clayshale.
T. S. 11366	Siltstone, occasional medium-grained quartz grains, clay matrix.
11366.5-11369	Sandstone, quartz arenite, very light gray, medium-grained, well-sorted, well-rounded, structureless, silica cement increasing upward, minor clay matrix at base, increased induration upward.
T. S. 11368	Sandstone, quartz arenite, fine- to medium-grained, moderately sorted, well-rounded, extensive quartz cementation, thin siltstone layer, low porosity.
11369-11369.5	No core.
	Deadwood Formation
11369.5-11385	Dolomite, light gray to yellowish gray, fossiliferous.

APPENDIX E. List of Conodonts from Lehigh Cement Company Wells (after Sweet, 1984, written communication)

Locality H-1 *	Sample Depth (in feet)										
Species	1326	1310	1295	1283	1279	1267	1266	1253	1250	1247	1174
Amorphognathus sp.										X	
Belodina compressa		X	X								
B. confluens								X	X	X	X
Dapsilodus mutatus									X	X	
Drepanoistodus suberectus	X	X	X	X	X	X	X	X	X	X	X
Erismodus quadridactylus											
'Oistodus' venustus									X	X	
Oulodus serratus	X	X	X	X	X						
Panderodus feulneri					X	X	X	X	X	X	X
P. gracilis	X	X	X	X							
Periodon grandis					X			X	X	X	X
Phragmodus cognitus	X	X	X	X							
P. undatus						X	X	X	X	X	X
Plectodina aculeata		X	X	X	X	X	X				
P. tenuis						X	X	X		X	X
Polyplacognathus ramosus		X	X								
Protopanderodus liripipus				X	X				X	X	X
Scyphiodus primus		X									
Staufferella sp.	X				X						

*Location: SE, Sec. 17, T. 143 N., R. 56 W.

Locality H-2 *	Sample Depth (in feet)									
Species	1559	1449	1446	1444	1436	1431	1430	1427	1418	1384
Belodina confluens							X	X	X	X
Bryantodina typicalis	?									
Chirognathus sp.		?								
Dapsilodus mutatus									X	X
Drepanoistodus suberectus	X	X	X		X	X	X	X	X	X
Erismodus quadridactylus			X							
'Oistodus' pseudoabundans	X									
'Oistodus' venustus								X	X	X
Oulodus serratus		X	X		X					
Panderodus feulneri							X	X	X	X
P. gracilis	X	X			X	X				
Periodon grandis							X	X	X	X
Phragmodus cognitus		X	X							
P. inflexus	X									
P. undatus					X	X	X	X	X	X
Plectodina aculeata		X	X		X					
P. dakota	X	X								
P. tenuis						X	X			X
Polyplacognathus ramosus	X	X								
Protopanderdus liripipus								X	X	X
Scyphiodus primus	X									
Staufferella sp.	X									X

*Location: SW, Sec. 23, T. 152 N., R. 56 W.

Locality H-3 *	Sample Depth (in feet)										
Species	849	848	838	827	780	760	757	754	753	725	693
Belodina compressa			X	X							
B. confluens										X	X
Chirognathus sp.					X	X					
Dapsilodus mutatus										X	
Drepanoistodus suberectus	X	X	X	X	X	X					
Erismodus quadridactylus					X	X	X	X			
Oulodus serratus					X	X			X		
Panderodus feulneri										X	
P. gracilus		X	X	X	X						
Phragmodus cognitus	X	X	X	X	X						
Plectodina aculeata					X	X	X	X	X		
P. tenuis											X
Polyplacognathus ramosus		X		X	X	X		X	X		
Protopanderodus liripipus										X	
Scyphiodus primus	X										
Staufferella sp.										X	

*Location: SWSW, Sec. 3, T. 151 N., R. 53 W.

Locality H-4 *	Sample Depth (in feet)											
Species	567	563	562	537	536	533	529	520	517	490	477	385
Belodina confluens						X	X	X	X	X	X	X
Chirognathus sp.			X									
Culumbodina occidentalis												X
Drepanoistodus suberectus		X	X	X	X	X	X	X	X	X	X	X
Erismodus quadridactylus		X	X									
'Oistodus' venustus						X		X				X
Oulodus serratus		X	X	X	X							
Oulodus sp.									X			
Panderodus feulneri						X	X		X	X	X	X
P. gracilis		X	X	X	X							
P. panderi							X					
Periodon grandis						X	X	X	X	X	X	
Phragmodus cognitus		X	X	X								
P. undatus					X	X	X	X	X			
Plectodina aculeata		X	X	X	X							
P. tenuis					X							
P. ? n. sp.						X		X				
Polyplacognathus ramosus			X	X	X							
Protopanderodus liripipus						X	X	X	X	X	X	
Staufferella sp.					X	X						
Walliserodus sp.												X

*Location: SWSW, Sec. 3, T. 151 N., R. 52 W.

Locality H-5 *	Sample Depth (in feet)			
Species	360	358	295	291
Belodina confluens	X	X	X	X
Drepanoistodus suberectus	X	X	X	X
'Oistodus' venustus		X		
Panderodus breviusculus			X	
P. feulneri	X	X	X	X
Periodon grandis	X		X	X
Phragmodus undatus		X		
Plectodina tenuis			X	
Protopanderodus liripipus	X	X	X	X
Staufferella sp.		X	X	

*Location: SWSW, Sec. 4, T. 151 N., R. 51 W.

Locality H-6 *	Sample Depth (in feet)					
Species	457	450	439	428	423	362
Belodina confluens				X	X	X
Chirognathus sp.	X					
Dapsilodus mutatus				X		
Drepanoistodus suberectus	X	X		X	X	
Erismodus quadridactylus		X	X			
'Oistodus' venustus				X		
Panderodus feulneri				X	X	X
P. panderi				X		
Periodon grandis				X	X	X
Phragmodus cognitus	X	X	X			
P. undatus					X	
Plectodina aculeata	X	X	X			
P. tenuis						X
Protopanderodus liripipus				X	X	X
Staufferella sp.					X	

*Location: SESE, Sec. 5, T. 151 N., R. 51 W.

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